SCS
NATIONAL
ENGINEERING
HANDBOOK

SECTION 15

IRRIGATION

Chapter 11

SPRINKLER IRRIGATION

July 1963

SOIL CONSERVATION SERVICE
UNITED STATES DEPARTMENT OF AGRICULTURE

The SCS National Engineering Handbook is intended primarily for Soil Conservation Service engineers. Engineers working in related fields will find much of its information useful to them also.

The handbook is being published in sections, each section dealing with one of the many phases of engineering included in the soil and water conservation program. For easy handling, some of the sections are being published by chapters. Publishing of either sections or chapters will not be in numerical order.

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Sprinkler Irrigation--Chapter 11, Section 15 (Irrigation)--describes the procedures and criteria for use in the design, installation, and operation of sprinkler irrigation systems.

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IRRIGATION

CHAPTER 11--SPRINKLER IRRIGATION

Application Principles

In the sprinkler method of irrigation, water is applied above the ground surface as a spray somewhat resembling rainfall. The spray is developed by the flow of water under pressure through small orifices or nozzles. The pressure is usually obtained by pumping, although it may be by gravity if the water source is high enough above the area irrigated.

With careful selection of nozzle sizes, riser heights, operating pressure, and sprinkler spacing, water can be applied uniformly at a rate based on the intake rate of the soil, thereby preventing runoff and the resulting damage to land and crops.

Adaptability of the Sprinkler Method

The sprinkler method is adapted to the irrigation of most crops. Rice is an exception.

It is also adaptable to nearly all irrigable soils since sprinklers are available in a wide range of discharge capacities. With proper spacing, water may be applied at any selected rate above 0.20 inch per hour. On extremely fine-textured soils with low intake rates, particular care is required in the selection of proper nozzle sizes, operating pressure, and sprinkler spacing to apply water uniformly at these low rates.

The flexibility of present-day sprinkler equipment and its efficient control of application make this method adaptable to most topographic conditions without extensive land preparation, subject only to limitations imposed by land use capability and economics.

Sprinkler irrigation can be adapted to most climatic conditions where irrigated agriculture is feasible; however, extremely high temperatures and wind velocities present problems in some areas. Where one or both of these conditions make it difficult to apply water uniformly and efficiently by the sprinkler method, one of the surface methods is generally used. This is the case in many arid areas in the West.

The use of the sprinkler method is questionable where irrigation water contains large amounts of dissolved salts.

Planning Procedure

A step-by-step checklist of the procedure normally used in planning a sprinkler irrigation system follows. Some of these steps are discussed in more detail in other chapters, and reference is made to the appropriate chapter.

Step 1. Make an inventory of available resources and operating conditions. Include information on soils, topography, water supply, source of power, crops, and farm operation schedules.

Step 2. Determine from the local irrigation guide, the depth or quantity of water to be applied at each irrigation. If there is no such guide, follow instructions in chapter 1, Soil-Water-Plant Relationships, to compute this depth.

Step 3. Determine design-use frequency of irrigation or shortest irrigation period. The needed information is available from the local irrigation guide; the procedure is discussed more fully in chapter 2, Irrigation-Water Requirements.

Step 4. Determine capacity requirements of the system.

Step 5. Determine optimum water-application rate. Maximum (not necessarily optimum) rates are obtainable from the local irrigation guide.

Step 6. Determine type of sprinkler required.

Step 7. Determine sprinkler spacing, discharge, nozzle sizes, and operating pressure for the optimum water-application rate.

Step 8. Determine number of sprinklers, operating simultaneously, required to meet system capacity requirements.

Step 9. Determine the best layout of main and lateral lines for simultaneous operation of about the required number of sprinklers.

Step 10. Make necessary final adjustments to meet layout conditions.

Step 11. Determine required sizes of lateral line pipe.

Step 12. Determine maximum total pressure required for individual lateral lines.

Step 13. Determine required sizes of main-line pipe.

Step 14. Check main-line pipe sizes for power economy.

Step 15. Determine maximum and minimum operating conditions.

Step 16. Select pump and power unit for maximum operating efficiency within range of operating conditions. The selection of a pump and power plant is discussed in chapter 8, Irrigation Pumping Plants.

Step 17. Prepare plans, schedules, and instructions for proper layout and operation.

Capacity Requirements

The required capacity of a sprinkler system depends on the size of the area irrigated (design area), the gross depth of water applied at each irrigation, and the net operating time allowed to apply this depth. The capacity of a system may be computed by the formula

$$Q = \frac{453\ Ad}{FH}$$

where Q = discharge capacity in gallons per minute
A = acreage of the design area
d = gross depth of application in acre-inches per acre
F = number of days allowed for completion of one irrigation
H = number of actual operating hours per day

F and H are of major importance in that they have a direct bearing on the capital investment per acre required for equipment. From the formula, it is obvious that the greater the product of these factors (operating time) the smaller the system capacity (and thereby the cost) will be for a given acreage. Conversely, where the farmer wishes to irrigate his acreage in a minimum number of days and has labor available only for operation during daylight hours, his equipment costs per acre will be higher.

Before a sprinkler system is planned, the designer should thoroughly acquaint the owner with these facts and should have a clear understanding with him on the number of operating hours that can be allowed for completing one irrigation. Available labor with a minimum of interference with other farming operations must always be considered.

The acreage discharge chart (fig. 11-1) may be used for the solution of this formula.

Design areas that have soil zones with significantly different values for moisture replacement can be subdivided on the basis of the water needed at each irrigation (fig. 11-2).

Sample calculation 11-1 has been prepared as an example of the use of the formula where a single crop is irrigated in the design area.

Gallons per minute, $Q = \dfrac{453 \times \text{Acres irrigated (A)} \times \text{Depth of water applied (d)}}{\text{Number of days (F)} \times \text{Hours per day (H)}}$

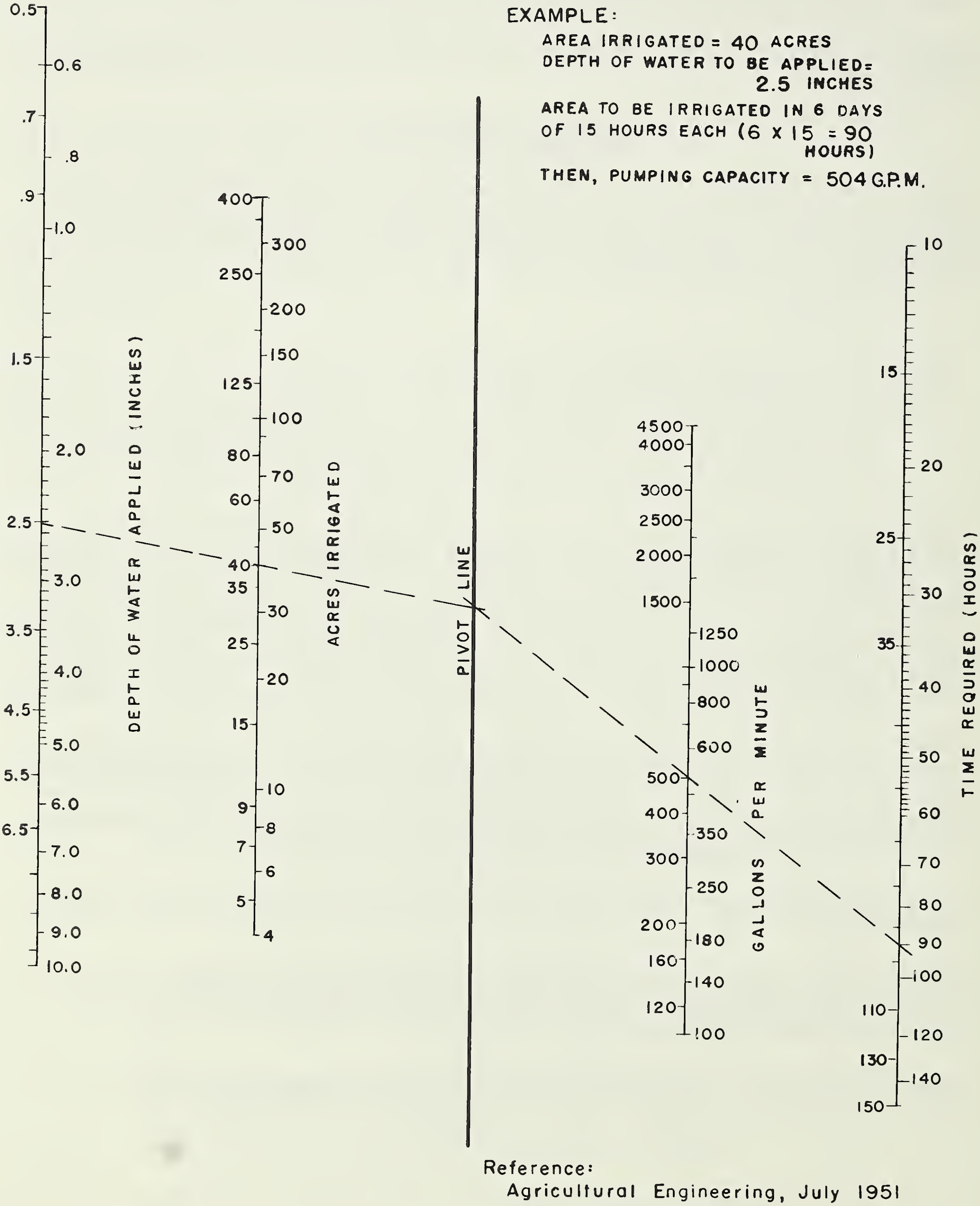
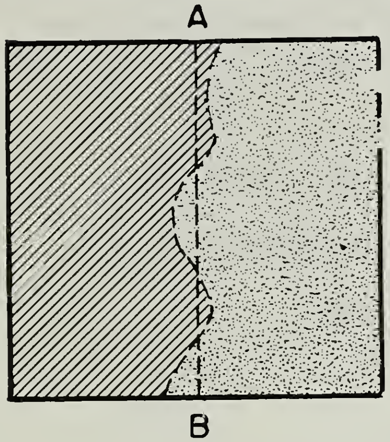


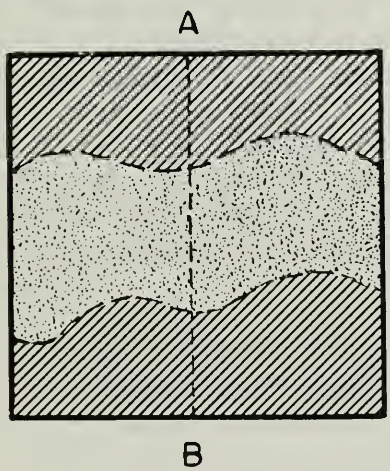
Figure 11-1.--Capacity requirements for irrigation systems.

3" REQUIRED AT EACH IRRIGATION

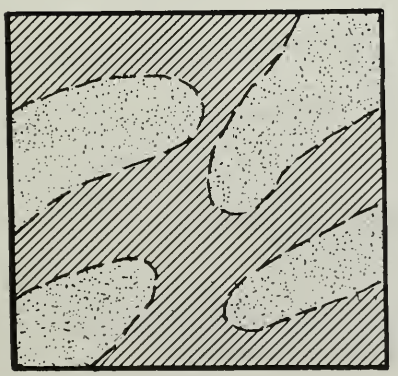
1 1/2" REQUIRED AT EACH IRRIGATION



A - The design area can be served by a main (A-B). One lateral operated for both sides, but run twice as long on the 3" zone and twice as often on the 1-1/2" zone---or by separate laterals designed with different water-application rates. In either case the frequency irrigation would be two times on the 1-1/ zone for each time on the 3" zone.



B - The system designed as for a uniform soil area using the 1-1/2" water-application rate. In operation the lateral or laterals could be operated twice as long on the 3" zone once during the early growing season, but the entire area irrigated by the frequency required for the 1-1/2" zone during peak-moisture use periods.



C - Again the system would be designed for the 1-1/2" zone. For deep-rooted crops, the entire area might be given a 3" application for the first irrigation in the spring. This would mean some sacrifice in water-application efficiency however.

Figure 11-2.--Subdivision of design areas having different soil zones.

Sample calculation 11-1.--Computing capacity requirements for a single crop in the design area

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Given:

40 acres of corn (A).
Design moisture use rate: 0.20 inch per day.
Moisture replaced in soil at each irrigation: 2.4 inches.
Irrigation efficiency: 70 percent.
Gross depth of water applied (d): 2.4/.70 or 3.4 inches at 70-percent efficiency.
Irrigation period (F): 10 days in a 12-day interval.
System to be operated 20 hours per day (H).

Calculation:

$$Q = \frac{453\ Ad}{FH} = \frac{453 \times 40 \times 3.4}{10 \times 20} = 308 \text{ gallons per minute}$$

Where two or more design areas with different crops are being irrigated by the same system and peak design-use rates for the crops occur at about the same time of the year, the capacity for each area is computed as shown in sample calculation 11-1, and capacities for each area are added together to obtain the required capacity of the system. The time allotted for completing one irrigation over all areas (F) must be no longer than the shortest irrigation-frequency period as taken from the local irrigation guide or as determined by the procedure in chapter 2, Irrigation-Water Requirements.

System-capacity requirements for a design area in a crop rotation are computed for the period of maximum requirements. Maximum requirement may, but not always, occur when all crops in the rotation are being irrigated. Allowances must be made for the differences in time when the peak-use requirements for each crop occur (sample calculation 11-2).

Sample calculation 11-2.--Computing capacity requirements for a crop rotation

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Given:

Design area of 90 acres with crop acreages as follows:
10 acres Irish potatoes, last irrigation May 31.
2.6-inch application lasts 12 days in May (peak period).
30 acres corn, last irrigation August 20.
2.9-inch application lasts 12 days in May.
3.4-inch application lasts 12 days in July (peak period).
50 acres alfalfa, irrigated through frost-free period.
3.6-inch application lasts 12 days in May.
4.3-inch application lasts 12 days in July (peak period).
Irrigation period is 10 days in 12-day irrigation interval.
System to be operated 16 hours per day.

Calculation:

Capacity requirements for May

$$Q = \frac{453Ad}{FH}$$

(All three crops are being irrigated)

Irish potatoes $Q = \frac{453 \times 10 \times 2.6}{10 \times 16}$ = 74 gallons per minute

Corn $Q = \frac{453 \times 30 \times 2.9}{10 \times 16}$ = 246 gallons per minute

Alfalfa $Q = \frac{453 \times 50 \times 3.6}{10 \times 16}$ = 510 gallons per minute

Total for May = 830 gallons per minute

Capacity requirements for July

$$Q = \frac{453\ Ad}{FH}$$

(Potatoes have been harvested, corn and alfalfa using moisture at peak rate.)

Corn $Q = \frac{453 \times 30 \times 3.4}{10 \times 16}$ = 289 gallons per minute

Alfalfa $Q = \frac{453 \times 50 \times 4.3}{10 \times 16}$ = 609 gallons per minute

Total for July = 898 gallons per minute

Although only two of the three crops are being irrigated, the maximum-capacity requirement of the system is in July.

Optimum Rates of Water Application

The rate at which water is applied depends on the following:

1. The time required for the soil to absorb the calculated depth of application without runoff for the given conditions of soil, slope, and cover. The depth of application divided by this required time is the maximum application rate.

2. The minimum application rate that will result in reasonably uniform distribution and satisfactory efficiency under prevalent climatic conditions.

3. The desirable time for applying the required depth of water considering efficient use of available labor and the other operations on the farm.

4. The application rate adjusted to the number of operating sprinklers using the best possible layout of lateral and main lines.

In all cases, the selected water-application rate must fall somewhere between maximum and minimum values.

The local irrigation guide sets forth suggested values for maximum water-application rates for different soils and for different slopes and cover. Maximum application rates for good ground cover should be used only when such cover can be established and maintained.

For most irrigated crops, the minimum practical rate of application to obtain reasonably good distribution and high efficiency is about 0.20 inch per hour under favorable climatic conditions. Where high temperatures and high wind velocities are common, the minimum application rate will be higher. To establish minimum application rates for local conditions requires experience and judgment.

Between maximum and minimum rates of application, the designer needs to consider the rate that requires a time of setting most nearly fitting the farm operation schedules. For small units, it is usually desirable to have intervals that give one, two, or three changes per day and that avoid afterdark changes. Changes just before or after mealtimes leave most of the day for other work.

Selection of Sprinkler

The two principal methods used to develop the spray required for sprinkling are (1) revolving head sprinklers having one, two, or three nozzles, depending primarily on the diameter of the wetted circle; and (2) pipe containing lines of small perforations along its top and sides.

Revolving head-sprinkler systems are classified according to pressure range and their position in relation to irrigated crops. A discussion of the different classifications, with the characteristics and adaptations of each, is in table 11-1.

Moisture-Distribution Patterns and Spacing Requirements

With the type of sprinkler determined, based on pressure limitations, application rates, cover conditions, crop requirements, and availability of labor, the next step is to determine the combination of sprinkler spacing, operating pressure, and nozzle sizes that will most nearly provide the optimum water-application rate with the greatest degree of uniformity of distribution.

The degree of uniformity obtainable depends primarily on the moisture-distribution pattern of the sprinkler and on the spacing of the sprinklers. When the sprinklers are properly spaced, the pattern from an individual sprinkler that results in the most nearly uniform depth of coverage has a cross section approaching a triangle in shape. Figure 11-3

Table 11-1.--Classification of sprinklers and their adaptability

Type of sprinkler	Low pressure 5-15 p. s. i.	Moderate pressure 15-30 p. s. i.	Intermediate pressure 30-60 p. s. i.	High pressure 50-100 p. s. i.	Hydraulic or giant 80-120 p. s. i.	Undertree low-angle 10-50 p. s. i.	Perforated pipe 4-20 p. s. i.
General characteristics	Special thrust springs or reaction-type arms.	Usually single-nozzle oscillating or long-arm dual-nozzle design.	Either single or dual nozzle design.	Either single or dual nozzle design.	One large nozzle with smaller supplemental nozzles to fill in pattern gaps. Small nozzle rotates the sprinkler.	Designed to keep stream trajectories below fruit and foliage by lowering the nozzle angle.	Portable irrigation pipe with lines of small perforations in upper third of pipe perimeter.
Range of wetted diameters	20 to 50 feet.	60 to 80 feet.	75 to 120 feet.	110 to 230 feet.	200 to 400 feet.	40 to 90 feet.	Rectangular strips 10 to 50 feet wide.
Recommended minimum application rate	0.40 inch per hour.	0.20 inch per hour.	0.25 inch per hour.	0.50 inch per hour.	0.65 inch per hour.	0.33 inch per hour.	0.50 inch per hour.
Jet characteristics (assuming proper pressure-nozzle size relations)	Waterdrops are large due to low pressure.	Waterdrops are fairly well broken.	Waterdrops are well broken over entire wetted diameter.	Waterdrops are well broken over entire wetted diameter.	Waterdrops are extremely well broken.	Waterdrops are fairly well broken.	Waterdrops are large due to low pressure.
Moisture distribution pattern (assuming proper spacing and pressure-nozzle size relations)	Fair.	Fair to good at upper limits of pressure range.	Very good.	Good except where wind velocities exceed 4 miles per hour.	Acceptable in calm air. Severely distorted by wind.	Fairly good. Diamond pattern recommended where laterals are spaced more than one tree interspace.	Good pattern is rectangular.
Adaptations and limitations.	Small acreages. Confined to soils with intake rates exceeding 0.50 inch per hour and to good ground cover on medium- to coarse-textured soils.	Primarily for undertree sprinkling in orchards. Can be used for field crops and vegetables.	For all field crops and most irrigable soils. Well adapted to overtree sprinkling in orchards and groves and to tobacco shades.	Same as for intermediate pressure sprinklers except where wind is excessive.	Adaptable to close-growing crops that provide a good ground cover. For rapid coverage and for odd-shaped areas. Limited to soils with high intake rates.	For all orchards or citrus groves. In orchards where wind will distort overtree sprinkler patterns. In orchards where available pressure is not sufficient for operation of overtree sprinklers.	For low-growing crops only. Unsuitable for tall crops. Limited to soils with relatively high intake rates. Best adapted to small acreages of high-value crops. Low operating pressure permits use of gravity or municipal supply.

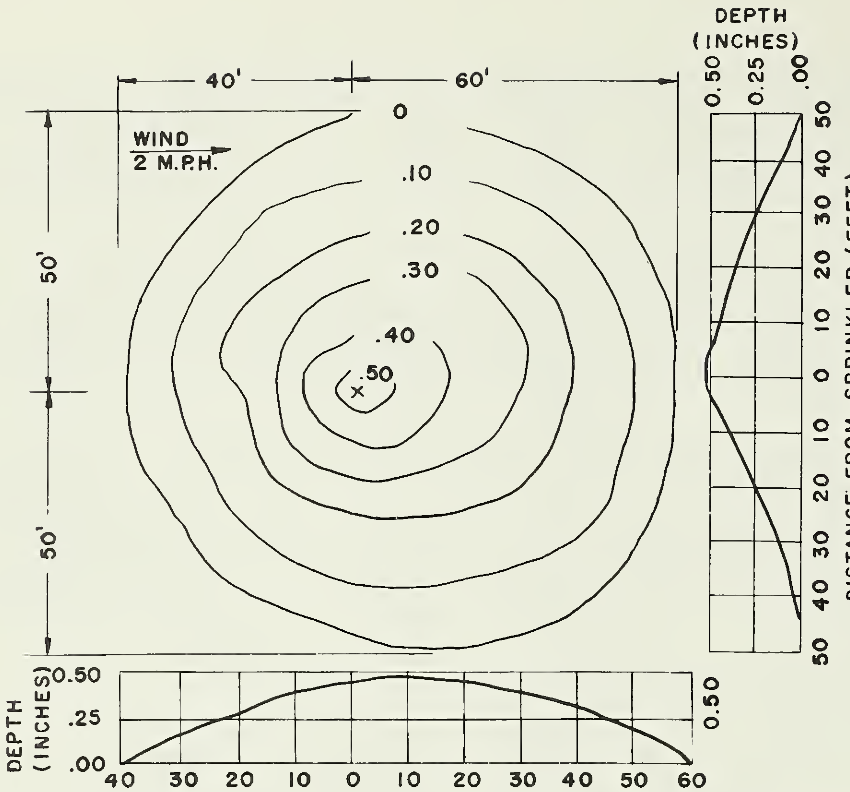


Figure 11-3.--Distribution pattern from sprinklers operating under favorable conditions.

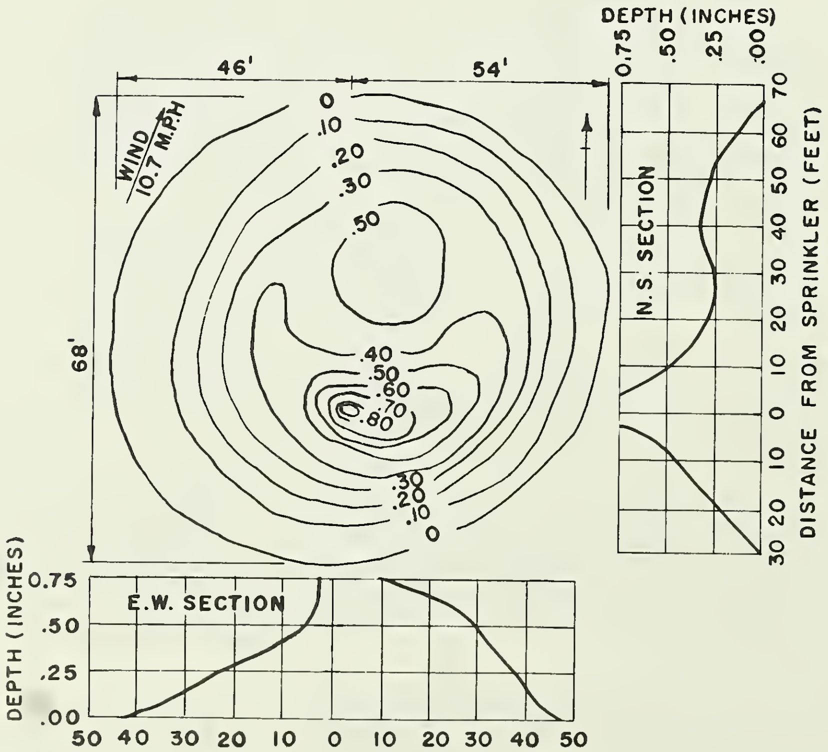


Figure 11-4.--Effect of wind on distribution pattern.

in a test shows the pattern obtained by a moderate pressure-type sprinkler operating under favorable conditions. These conditions are (1) proper operating pressure for the nozzle sizes selected and (2) absence of wind.

Each type of sprinkler has certain pattern characteristics that change as nozzle size and operating pressure change. Each has an optimum range of operating pressures for each nozzle size. In selecting nozzle sizes and operating pressure for a required sprinkler discharge, the different pressures affect the pattern as follows:

1. At the lower side of the specified pressure range for any nozzles, the water is broken up into larger drops. When pressure falls too low, the water from the nozzle falls in a ring a distance away from the sprinkler, thus giving a poor moisture-distribution pattern (fig. 11-5,A.)
2. On the high side of the pressure range, the water from the nozzle breaks up into finer drops and settles around the sprinkler (fig. 11-5, C). Under such conditions the pattern is easily distorted by wind movement.
3. Within the desirable range, the sprinkler should produce the distribution of water shown in figure 11-5, B.

For a given pressure, larger drops are obtained from a large nozzle size and fine spray from a small nozzle. All manufacturers of revolving sprinklers recommend operating pressures or ranges of pressures for each type of sprinkler and nozzle size that will result in the most desirable application pattern.

Wind distorts the application pattern and the higher the wind velocity, the greater the distortion. Figure 11-4 shows test results of an intermediate pressure-type sprinkler operating under a wind velocity of 10.7 miles per hour. This distortion must be considered when selecting the sprinkler spacing.

The depth of water applied to an area surrounding a revolving sprinkler decreases as the distance from the sprinkler increases. Thus, to obtain a reasonably high degree of uniformity of application, water from adjacent sprinklers must be added. Figure 11-6 illustrates the aggregate depth distribution obtained by overlapping.

Manufacturers of sprinklers specify a wetted diameter for all nozzle-size and operating pressure combinations for each type of sprinkler in their line. Since it is common for sprinkler-spacing recommendations to be made on the basis of these diameters, they must be carefully considered by the planner.

Obviously, whenever the spacing of sprinklers on the lateral (S_l) or the spacing of laterals along the main line (S_m) is changed, the extent of overlap of the sprinklers contributing to the water falling in a given area

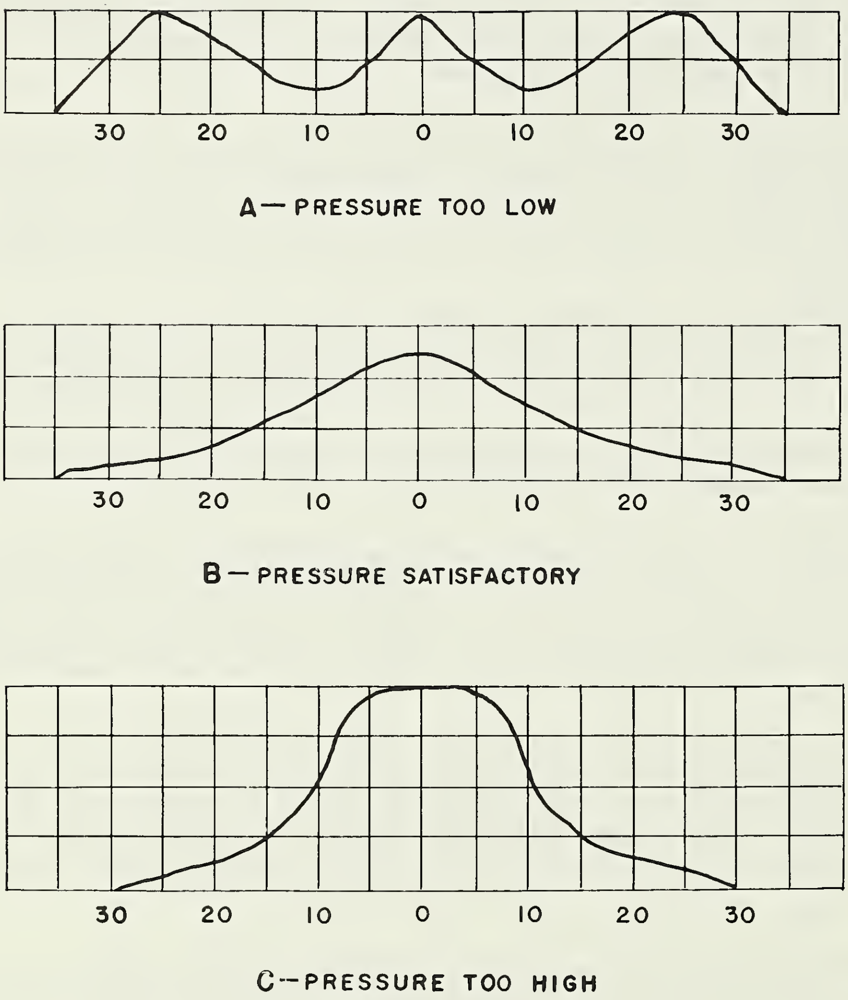


Figure 11-5.--Effect of different pressures on distribution pattern.

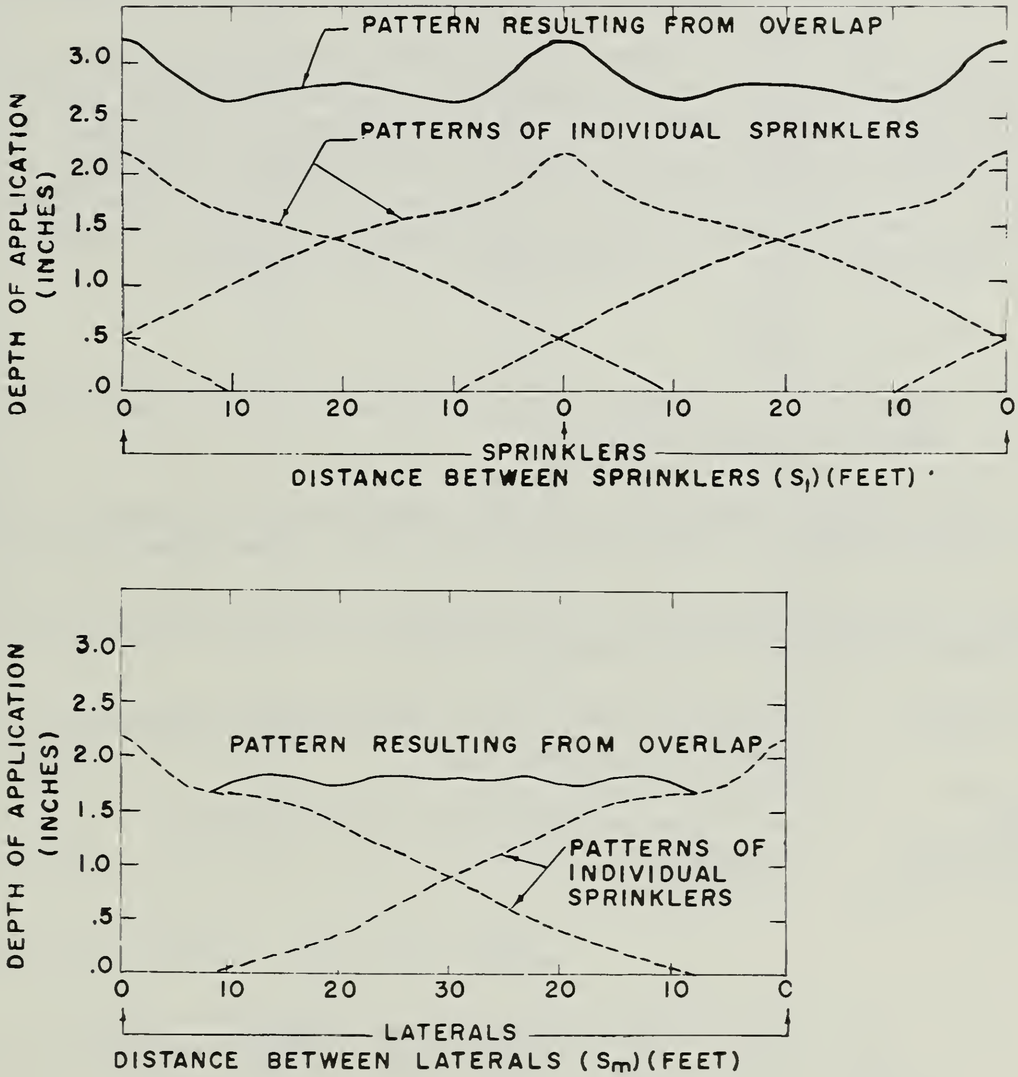


Figure 11-6.--Distribution pattern resulting from overlapping sprinklers.

also changes. Therefore, different spacings result in different degrees of uniformity.

Sprinklers may be spaced either in a triangular, rectangular, or square arrangement. All of these prove satisfactory where adequate overlap is provided. Square and rectangular spacings are more common. Triangular spacings result from staggering sprinkers along alternate lateral lines.

A measurable index of the degree of uniformity obtainable for any size sprinkler operating under given conditions has been adopted and is known as the uniformity coefficient (C_u). This uniformity coefficient is affected by pressure-nozzle size relations, by sprinkler spacing, and by wind conditions. The coefficient is computed from field observations of the depths of water caught in open cans placed at regular intervals within a sprinkled area. It is expressed by the equation

$$C_u = 100 \left(1.0 - \frac{\Sigma X}{mn}\right)$$

where X = deviation of individual observations from the mean value (m)
n = number of observations

An absolutely uniform application would then have a uniformity coefficient of 100 percent; a less uniform application some lower percentage.

An example of the calculations for determining the uniformity coefficient from a typical field test is shown as follows:

Sprinkler:	9/32x3/16 inch - 25.2 gallons per minute at 60 pounds per square inch
Spacing:	60 by 60 feet
Wind:	2.4 miles per hour from the southeast
Humidity:	36 percent
Time of test:	1.0 hour

NORTH

	X	0.62	0.52	0.52	0.66	0.67	X	
	0.59	.59	.62	.60	.69	.77	0.70	
	.57	.50	.66	.63	.70	.47	.56	
WEST	.59	.61	.72	.75	.64	.47	.49	EAST
	.68	.74	.63	.60	.42	.56	.63	
	.48	.80	.57	.49	.58	.40	.51	
	X	.61	.52	.52	.65	.63	X	

SOUTH

Observations	Number (n)	Total	Deviations (x)	Total (x)
0.40	1	0.40	0.20	0.20
.42	1	.42	.18	.18
.47	2	.94	.13	.26
.48	1	.48	.12	.12
.49	2	.98	.11	.22
.50	1	.50	.10	.10
.51	1	.51	.09	.09
.52	4	2.08	.08	.32
.56	3	1.68	.04	.12
.57	2	1.14	.03	.06
.58	1	.58	.02	.02
.59	3	1.77	.01	.03
(m) .60	2	1.20	---	---
.61	2	1.22	.01	.02
.62	2	1.24	.02	.04
.63	3	1.89	.03	.09
.64	1	.64	.04	.04
.65	1	.65	.05	.05
.66	2	1.32	.06	.12
.67	1	.67	.07	.07
.68	1	.68	.08	.08
.69	1	.69	.09	.09
.70	2	1.40	.10	.20
.72	1	.72	.12	.12
.74	1	.74	.14	.14
.75	1	.75	.15	.15
.77	1	.77	.17	.17
.80	1	.80	.20	.20
Totals	n = 45	26.86		$\Sigma X = 3.30$

$$\text{Mean, } m = \frac{26.86}{45} = .597, \text{ use } .60$$

$$C_u = 100\left(1 - \frac{3.30}{26.86}\right) = 87.7 \text{ percent}$$

The leading manufacturers of revolving sprinklers are continually making such field tests of their products, and a good many data on several sprinklers, operating under various field conditions, are now available. Undoubtedly many more data will be available in the future. Service personnel planning sprinkler-irrigation systems should request such data from the distributors or manufacturers. Where such data are available, they should be used as a basis for selecting that combination of spacing, discharge, nozzle size, and operating pressure that will result in the highest uniformity coefficient possible under existing operating conditions. Uniformity coefficients of 85 percent or greater are acceptable.

For a more detailed discussion of uniformity coefficients, the reader is referred to University of California Bulletin 670, Irrigation Sprinkling, by J. E. Christiansen, 1942.

In the absence of data on uniformity coefficients, the following maximum spacing criteria will be used for all sprinkler systems planned by personnel of the Soil Conservation Service.

1. For low, moderate, and intermediate pressure sprinklers, the spacing along lateral lines (S_l) shall not exceed 50 percent of the wetted diameter as given in the manufacturers performance tables when the sprinkler is operating under optimum pressure. The spacing of laterals along the main line (S_m) shall not exceed 65 percent of this wetted diameter. Where wind can be expected, spacing (S_m) shall be reduced to 50 percent for average velocities of 5 to 10 miles per hour and to 30 percent for average velocities greater than 10 miles per hour.
2. For high-pressure sprinklers and for the giant hydraulic type, the <u>maximum</u> (diagonal) distance between two sprinklers on adjacent lateral lines should not exceed two-thirds of the wetted diameter under favorable operating conditions. Where winds in excess of 5 miles per hour can be expected, this spacing should be decreased as discussed in the preceding paragraph. The sprinkler spacing, or values of (S_l) and (S_m), are assumed and the diagonal distance computed as follows:

For square or rectangular spacing

$$S_d = \sqrt{S_l^2 + S_m^2}$$

Where sprinklers on alternate laterals are staggered

$$S_d = \sqrt{(1/2S_l)^2 + S_m^2}$$

This computed diameter is then compared with two-thirds of the wetted diameter quoted by the manufacturer.

Straight riser pipe, located between the sprinkler head and the lateral line pipe, must be provided in order to remove the turbulence set up when the direction of flow is changed by diversion of a part of the flow to an individual sprinkler. If not removed, this turbulence will carry through the nozzle and cause a premature stream breakup and a reduced diameter of coverage and thereby a poorer distribution pattern. The length of pipe needed to remove turbulence varies with sprinkler discharge. Recommended <u>minimum</u> riser lengths follow:

Discharge, G.P.M.	Risers	Discharge, G.P.M.	Risers
Under 10	6-inch	50-120	18-inch
10-25	9-inch	More than 120	36-inch
25-50	12-inch		

Discharge Requirements and Nozzle Sizes

The required discharge of an individual sprinkler is a function of the water-application rate and the two-way spacing of the sprinklers (table 11-2). The formula for computing this required discharge is

$$Q = \frac{S_l \times S_m \times I}{96.3}$$

where Q = required sprinkler discharge in gallons per minute
S_l = spacing of sprinklers along laterals in feet
S_m = spacing of laterals along main line in feet
I = optimum application rate in inches per hour

For perforated pipelines, the spacing recommendations made by the manufacturer for the optimum application rate, number and size of perforations, and operating pressure used should be followed. These recommendations can be obtained directly from manufacturers' performance tables. While no overlap is specifically required, it is necessary to space the lines sufficiently close together that each wetted strip meets adjacent ones and no dry area is left in between. To assure that the wetted areas meet, it is customary to allow an overlap of 2 to 4 feet.

With the optimum application rate fixed and the type of sprinkler chosen, the final selection of spacing, sprinkler discharge, nozzle size, and operating pressure becomes a trial and modification procedure. Common practice is to assume a sprinkler spacing and determine the sprinkler discharge from table 11-2. Next, nozzle size or sizes, optimum operating pressure, and diameter of the wetted circle are obtained from the manufacturer's sprinkler performance tables. The assumed spacing is then compared with the wetted diameter to assure that the required spacing criteria has been met. If it has not, a different spacing may be assumed or a different nozzle size-operating pressure combination selected and the procedure repeated.

Sample calculation 11-3, A, B, and C illustrate this selection procedure. In this calculation three of the leading manufacturers of revolving sprinkler heads have been designated as A, B, and C.

Sample calculation 11-3.--Selection of sprinkler spacing, discharge, nozzle sizes, and pressure

SAMPLE A

Given:

Sandy loam soil. Maximum allowable application rate: 0.65 inch per hour.
Field crops.
Intermediate pressure range desirable. Drops should be fairly well broken.
Wind velocities often reach 10 miles per hour.

Table 11-2.--Required sprinkler discharge rates for common spacings at given rates of application

Sprinkler spacing (feet)	0.15 Inch	0.20 Inch	0.25 Inch	0.30 Inch	0.35 Inch	0.40 Inch	0.45 Inch	0.50 Inch	0.55 Inch	0.60 Inch	0.65 Inch	0.70 Inch	0.75 Inch	0.80 Inch	0.90 Inch	1.00 Inch	1.10 inches	1.20 inches	1.30 inches	1.40 inches	1.50 inches	1.60 inches	1.70 inches	1.80 inches	2.00 inches
	Application rate per hour of-																								
	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.
20x20	0.62	0.83	1.04	1.25	1.46	1.66	1.87	2.08	2.29	2.50	2.70	2.91	3.12	3.33	3.74	4.16	4.58	4.99	5.41	5.82	6.24	6.66	7.07	7.49	8.32
20x30	.94	1.25	1.56	1.87	2.18	2.50	2.81	3.12	3.43	3.74	4.06	4.37	4.68	4.99	5.62	6.24	6.86	7.49	8.11	8.74	9.36	9.98	10.61	11.23	12.48
20x40	1.24	1.66	2.08	2.50	2.91	3.33	3.74	4.16	4.58	4.99	5.41	5.82	6.24	6.66	7.49	8.32	9.15	9.98	10.82	11.65	12.48	13.31	14.14	14.98	16.64
20x50	1.56	2.08	2.60	3.12	3.64	4.16	4.68	5.20	5.72	6.24	6.76	7.28	7.80	8.32	9.36	10.40	11.44	12.48	13.52	14.56	15.60	16.64	17.68	18.72	20.80
20x60	1.87	2.50	3.12	3.74	4.37	4.99	5.62	6.24	6.86	7.49	8.11	8.74	9.36	9.98	11.23	12.48	13.73	14.98	16.22	17.47	18.72	19.97	21.22	22.46	24.96
25x25	.98	1.30	1.63	1.95	2.28	2.60	2.93	3.25	3.58	3.90	4.23	4.55	4.88	5.20	5.85	6.50	7.15	7.80	8.45	9.10	9.75	10.40	11.05	11.70	13.00
30x30	1.40	1.87	2.34	2.81	3.28	3.74	4.21	4.68	5.15	5.62	6.08	6.55	7.02	7.49	8.42	9.36	10.30	11.23	12.17	13.10	14.04	14.98	15.91	16.85	18.72
30x40	1.87	2.50	3.12	3.74	4.37	4.99	5.62	6.24	6.86	7.49	8.11	8.74	9.36	9.98	11.23	12.48	13.73	14.98	16.22	17.47	18.72	19.97	21.22	22.46	24.96
30x50	2.34	3.12	3.90	4.68	5.46	6.24	7.02	7.80	8.58	9.36	10.14	10.92	11.70	12.48	14.04	15.60	17.16	18.72	20.28	21.84	23.40	24.96	26.52	28.08	31.20
30x60	2.81	3.74	4.68	5.62	6.55	7.49	8.42	9.36	10.30	11.23	12.17	13.10	14.04	14.98	16.85	18.72	20.59	22.46	24.34	26.21	28.08	29.95	31.82	33.70	37.44
40x40	2.50	3.33	4.16	4.99	5.82	6.66	7.49	8.32	9.15	9.98	10.82	11.65	12.48	13.31	14.98	16.64	18.30	19.97	21.63	23.30	24.96	26.62	28.29	29.95	33.28
40x50	3.12	4.16	5.20	6.24	7.28	8.32	9.36	10.40	11.44	12.48	13.52	14.56	15.60	16.64	18.72	20.80	22.88	24.96	27.04	29.12	31.20	33.28	35.36	37.44	41.60
40x60	3.74	4.99	6.24	7.49	8.74	9.98	11.23	12.48	13.73	14.98	16.22	17.47	18.72	19.97	22.46	24.96	27.46	29.95	32.45	34.94	37.44	39.94	42.43	44.93	49.92
40x80	4.99	6.66	8.32	9.98	11.65	13.31	14.98	16.64	18.30	19.97	21.63	23.30	24.96	26.62	29.95	33.28	36.61	39.94	43.26	46.56	49.92	53.25	56.58	59.90	66.56
50x50	3.90	5.20	6.50	7.80	9.10	10.40	11.70	13.00	14.30	15.60	16.90	18.20	19.50	20.80	23.40	26.00	28.60	31.20	33.80	36.40	39.00	41.60	44.20	46.80	52.00
50x60	4.68	6.24	7.80	9.36	10.92	12.48	14.04	15.60	17.16	18.72	20.28	21.84	23.40	24.96	28.08	31.20	34.32	37.44	40.56	43.68	46.80	49.92	53.04	56.16	62.40
50x70	5.46	7.28	9.10	10.92	12.74	14.56	16.38	18.20	20.02	21.84	23.66	25.48	27.30	29.12	32.76	36.40	40.04	43.68	47.32	50.96	54.60	58.24	61.88	65.52	72.80
50x80	6.24	8.32	10.40	12.48	14.56	16.64	18.72	20.80	22.88	24.96	27.04	29.12	31.20	33.28	37.44	41.60	45.76	49.92	54.08	58.24	62.40	66.56	70.72	74.88	83.20
50x90	7.02	9.36	11.70	14.04	16.38	18.72	21.06	23.40	25.74	28.08	30.42	32.76	35.10	37.44	42.12	46.80	51.48	56.16	60.84	65.52	70.20	74.88	79.56	84.24	93.60
50x100	7.80	10.40	13.00	15.60	18.20	20.80	23.40	26.00	28.60	31.20	33.80	36.40	39.00	41.60	46.80	52.00	57.20	62.40	67.60	72.80	78.00	83.20	88.40	93.60	104.00
60x60				11.23	13.10	14.98	16.85	18.72	20.59	22.46	24.34	26.21	28.08	29.95	33.70	37.44	41.18	44.93	48.67	52.42	56.16	59.90	63.65	67.39	74.88
60x80				14.98	17.47	19.97	22.46	24.96	27.46	29.95	32.45	34.94	37.44	39.94	44.93	49.92	54.91	59.90	64.90	69.89	74.88	79.87	84.86	89.86	99.84
60x90				16.85	19.66	22.46	25.27	28.08	30.89	33.70	36.50	39.31	42.12	44.93	50.54	56.16	61.78	67.39	73.01	78.62	84.24	89.86	95.47	101.09	112.32
60x100				18.72	21.84	24.96	28.08	31.20	34.32	37.44	40.56	43.68	46.80	49.92	56.16	62.40	68.64	74.88	81.12	87.36	93.60	99.84	106.08	112.32	124.80
60x120				22.46	26.21	29.95	33.70	37.44	41.18	44.93	48.67	52.42	56.16	59.90	67.39	74.88	82.37	89.86	97.34	104.8	112.3	119.8	127.3	134.8	149.8
80x80						26.62	29.95	33.28	36.61	39.94	43.26	46.59	49.92	53.24	59.90	66.56	73.22	79.87	86.53	93.18	99.84	106.5	113.2	119.8	133.1
80x90						29.95	33.70	37.44	41.18	44.93	48.67	52.42	56.16	59.90	67.39	74.88	82.37	89.86	97.34	104.8	112.3	119.8	127.3	134.8	149.8
80x100						33.28	37.44	41.60	45.76	49.92	54.08	58.24	62.40	66.56	74.88	83.20	91.52	99.84	108.2	116.5	124.8	133.1	141.4	149.8	166.4
80x120						39.94	44.93	49.92	54.91	59.90	64.90	69.89	74.88	79.87	89.86	99.84	109.8	119.8	129.8	139.8	149.8	159.7	169.7	179.7	199.7
80x140						46.59	52.42	58.24	64.06	69.89	75.71	81.54	86.36	93.18	104.8	116.5	128.1	139.8	151.4	163.1	174.7	186.4	198.0	209.7	233.0
80x160						53.25	59.90	66.56	73.22	79.87	86.53	93.18	99.84	106.5	119.8	133.1	146.4	159.7	173.1	186.4	199.7	213.0	226.3	239.6	266.2
100x100								52.00	57.20	62.40	67.60	72.80	78.00	83.20	93.60	104.0	114.4	124.8	135.2	145.6	156.0	166.4	176.8	187.2	280.0
120x120								74.88	82.37	89.86	97.34	104.8	112.3	119.8	134.8	149.8	164.7	179.7	194.7	209.7	224.6	239.6	254.6	269.6	299.5
140x140								101.9	112.1	122.3	132.5	142.7	152.9	163.1	183.5	203.8	224.2	244.6	265.0	285.4	305.8	326.1	346.5	366.9	407.7
160x160								133.1	146.4	159.7	173.1	186.4	199.7	213.0	239.6	266.2	292.9	319.5	346.1	372.7	399.4	426.0	452.6	479.2	532.5
180x180								168.5	185.3	202.2	219.0	235.9	252.7	269.6	303.3	337.0	370.7	404.4	438.0	471.7	505.4	539.1	572.8	606.5	
200x200								208.0	228.8	249.6	270.4	291.2	312.0	332.8	374.4	416.0	457.6	499.2	540.8	582.4					
220x220								251.7	276.8	302.0	327.2	352.4	377.5	402.7	453.0	503.4	553.7	604.0							
240x240								299.5	329.5	359.4	389.4	419.3	449.3	479.2	539.1	599.0									

For other spacings and/or application rates:

$$Q = \frac{S_l \times S_m \times I}{96.3} \quad \text{where}$$

Q = required sprinkler discharge in g.p.m.
S_l = spacing of sprinklers on lateral in feet
S_m = spacing of laterals on main line in feet
I = application rate in inches per hour

Use as wide a spacing as possible within pressure range and within limitations caused by wind velocities. Maximum diagonal spacing under windy conditions: 0.50 wetted diameter. Stagger sprinklers on alternate laterals.

Assume:

Sprinkler spacing: S_1 = 60 feet and S_m = 80 feet for operation when wind is not blowing. Assume an application rate of 0.50 inch per hour. This is less than optimum to permit a higher rate when lateral lines must be spaced closer together during windy periods.

Calculation:

From table 11-2 find sprinkler discharge to be 25 gallons per minute with a 60 by 80 foot spacing and an application rate of 0.50 inch per hour.

From manufacturer's sprinkler performance tables, select nozzle sizes, operating pressure, and diameter of wetted circle as follows:

Manufacturer	Nozzle size	Operating pressure	Wetted diameter
	Inches	*P.s.i.*	*Feet*
A.............	9/32x7/32	50	130
B.............	5/16x7/32	45	150
C.............	9/32x7/32	54	134

Compute the required wetted diameter, using criteria for calm conditions.

$$\sqrt{(1/2\ S_1)^2 + S_m^2} \times \frac{3}{2} = \sqrt{30^2 + 80^2} \times \frac{3}{2} = 128 \text{ feet}$$

It will be noted that all of these sprinklers will have a wetted diameter equal to or greater than the minimum required; thus each will satisfy the spacing criteria.

For windy conditions, the spacing between lateral lines (S_m) will have to be reduced to 60 feet in order not to exceed 0.50 times the wetted diameter. With the same sprinkler discharge and a 60 by 60-foot spacing, the application rate is 0.667 inch per hour (table 11-2). This is close enough to the maximum allowable rate. Thus the system may be operated under both calm and windy conditions by varying the lateral spacing.

In actual practice, however, the lateral line would, more often than not, be designed for windy conditions and operated with the same spacing (S_m) for all conditions.

SAMPLE B

Given:

Sandy loam soil, optimum application rate: 0.50 inch per hour.
Peach orchard. Moderate pressure, undertree type sprinkler desirable.
Tree spacing: 20 by 30 feet.
Wind velocities in orchard: less than 5 miles per hour.

Assume:

Sprinkler spacing: S_1 = 20 feet and S_m = 30 feet.

Calculation:

From table 11-2, find sprinkler discharge rate to be 3.12 gallons per minute with a 20 by 30-foot spacing and an application rate of 0.50 inch per hour.

From the manufacturer's sprinkler performance tables, select the nozzle size, operating pressure, and diameter of the wetted circle as follows:

Manufacturer	Nozzle size	Operating pressure	Wetted diameter
	Inches	*P.s.i.*	*Feet*
A.............	5/32 low angle	21	55
B.............	5/32 low angle	18	52
C.............	5/32 low angle	22	56

Compute the required wetted diameter to be $\frac{30 \text{ feet}}{.65} = 46$ feet.

It will be noted that all these sprinklers have a wetted diameter greater than the minimum required; thus each will satisfy the minimum spacing criteria.

SAMPLE C

Given:

Sandy loam soil. Optimum application rate under good cover conditions: 0.75 inch per hour.

Pasture grasses and hay crops.

Available labor on dairy farm is limited. Use high pressure sprinklers at a wide spacing to minimize pipe-moving requirements.

Assume:

Sprinkler spacing: $S_1 = 80$ feet and $S_m = 120$ feet. Stagger sprinklers in alternate laterals.

Calculation:

From table 11-2, find sprinkler discharge rate to be 75 gallons per minute with a spacing of 80 by 120 feet and an application rate of 0.75 inch per hour.

From manufacturer's sprinkler performance tables, select the nozzle sizes, operating pressure, and diameter of the wetted circle as follows:

Manufacturer	Nozzle size	Operating pressure	Wetted diameter
	Inches	*P.s.i.*	*Feet*
A.............	1/2x1/4	75	191
B.............	1/2x7/32	72	196
C.............	1/2x____	75	210

Determine the minimum required wetted diameter to be

$$\sqrt{(1/2\ S_1)^2 + S_m^2} \times \frac{3}{2} = \sqrt{40^2 + 120^2} \times \frac{3}{2} = 190 \text{ feet}$$

Note that all of these sprinklers have a wetted diameter greater than the minimum required, thus each will satisfy the maximum spacing criteria.

Types of Systems

Farm Systems. A complete farm sprinkler system can be defined as a system planned exclusively for a given design area or farm unit on which sprinkling will be the primary method of water application. Planning for complete systems will include consideration of specified crops and crop rotations and of the soils in the specified design area.

A farm sprinkler irrigation system includes all sprinkler lines, main lines and submains, pumping plant and boosters, operation-control equipment, and other accessories required for the efficient application of water. The system shown in figure 11-7 is of the semipermanent type having buried main lines and multiple sprinkler laterals operating in rotation around the mains.

Field Systems. A field system is designed either for use on several fields of a farm unit or for movement between fields on several farm units. Field systems are planned for stated conditions, generally for preirrigation, for bringing up seedings, or for use on specialty crops in a crop rotation. Considerations of distribution efficiency, labor utilization, and power economy may be entirely different for field systems than for complete farm systems. Field systems can be fully portable (fig. 11-8, A) or semiportable (fig. 11-8, B).

Expansion from Field to Farm System. Failure to recognize the fundamental difference between field and farm systems, either by the planner or the owner, has led to poorly planned systems of both kinds. In between these two is the incomplete farm system, initially used as a field system but later intended to become a part of a complete farm system.

Failure to recognize the needs of the ultimate system has led to many piecemeal systems with poor distribution efficiencies, excessive initial costs, and high annual water-application charges. This situation is not always the fault of the system planner, since he may not always be informed as to whether future expansion is intended; however, he has a responsibility to inform the owner of possible considerations for future development when he prepares a field-system plan.

Fully Portable Systems. A fully portable system has portable sprinkler lines, portable main lines and submains, and a portable pumping plant (fig. 11-8,A). Such a system is designed to be moved from field to field or to different pump sites in the same field on an individual farm unit or from farm to farm.

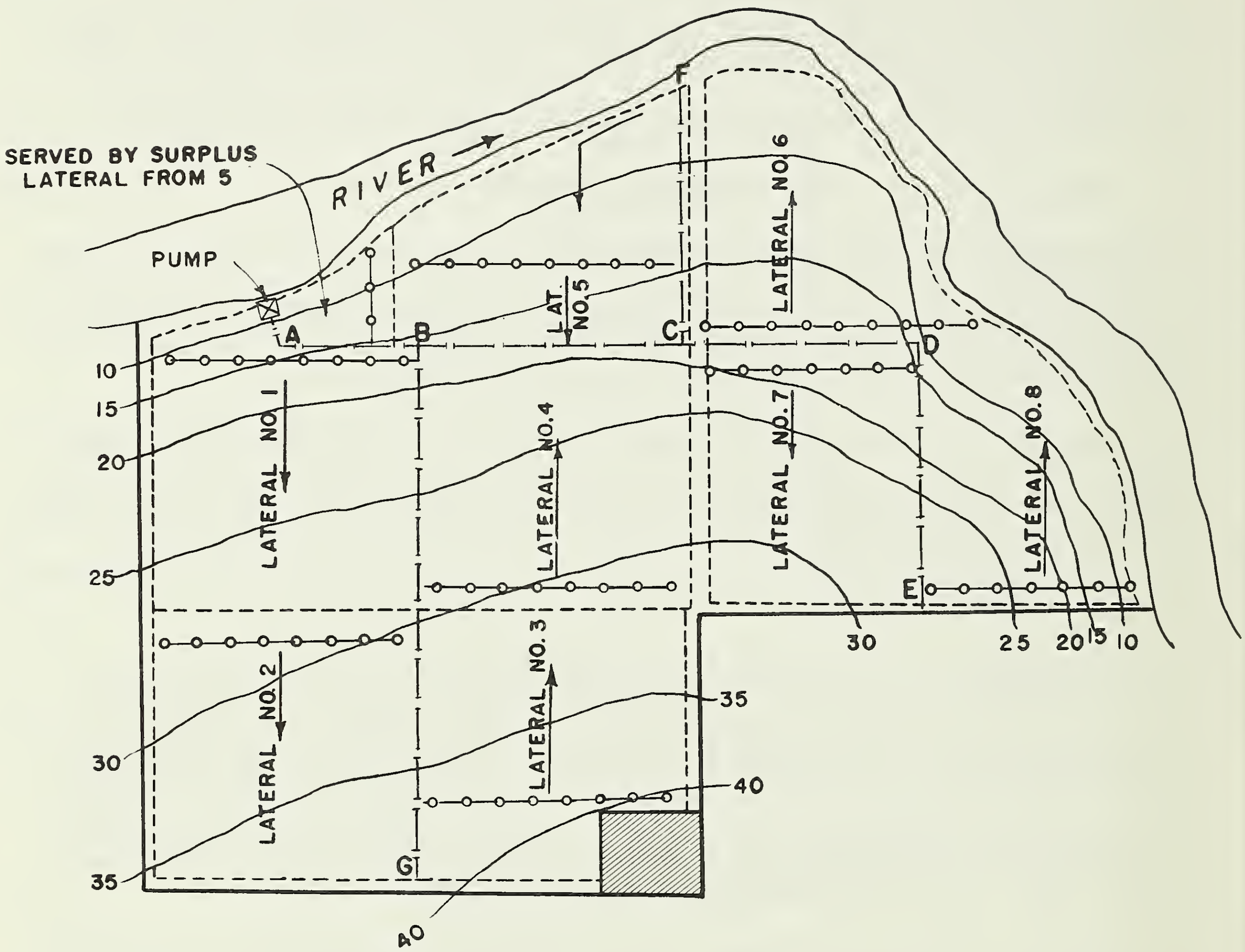


Figure 11-7.--Layout of a complete farm sprinkler system. The odd-shaped area of 72 acres illustrates the subdivision of the design area to permit rotation of all areas except one small tract near the pumping location. Number of sprinklers required per acre, 1-1/2; number of settings for each lateral per irrigation, 10; required number of sprinklers, 72x1.5 or 108; total sprinklers required for the eight laterals, 124. Lateral 8 will require an intermediate pressure-control valve.

Use of fully portable systems usually include one or more of the following:

1. Irrigation, by sprinkling, one crop such as tobacco, potatoes, or sugar beets, grown in rotation with other crops, such as alfalfa or grain, which is either irrigated by surface methods or not irrigated at all.
2. Sprinkler irrigation of pasture grass or hay crop seedings that are to be irrigated ultimately by surface methods.
3. Preirrigation and germination irrigation of sugar beets and truck crops later irrigated by surface methods.
4. Protection against frost or freezing.

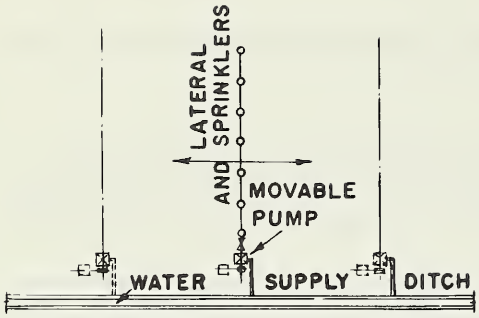
Semiportable Systems. A semiportable system is the same as a fully portable system except that the location of the water source and pumping plant are fixed (fig. 11-8, B). Such a system cannot be moved from field to field or from farm to farm except where more than one stationary pumping plant is utilized. It can, however, be used in more than one field provided the required length of main line is not excessive. The water-supply source is usually a well or an impounding reservoir or small lake.

Semipermanent Systems. A semipermanent system has portable sprinkler lines, permanent main lines, and a stationary pumping plant (fig. 11-8, C). The main lines and submains are usually buried. This type is used for such crops as orchards, groves, and permanent pasture that are to be irrigated permanently by sprinklers. These systems are also used when the entire farm is to be sprinkler irrigated and field boundaries are fixed.

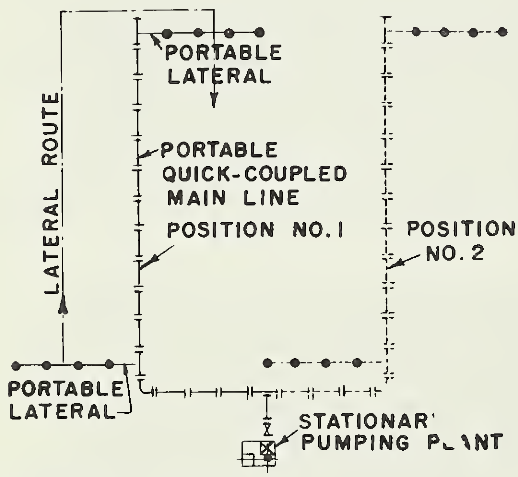
Another type of semipermanent system is made up of portable hose lines containing sprinklers, permanent main lines and submains, and a stationary pumping plant (fig. 11-8, D). Such a system is adapted to odd-shaped areas that are to be irrigated permanently, usually orchards or groves with undertree sprinklers. The hose lines provide flexibility and make it possible to maintain operation of the required number of sprinklers in spite of small odd-shaped corners.

Fully Permanent Systems. A fully permanent system is made up of permanent sprinkler lines, permanent main lines and submains, and a stationary pumping plant (fig. 11-8, E). Both laterals and mains are usually buried. The sprinklers may be permanently located or be moved from one location to another along the lateral lines. Lateral lines are provided with hydrant valves at each sprinkler location when the sprinklers are not stationary.

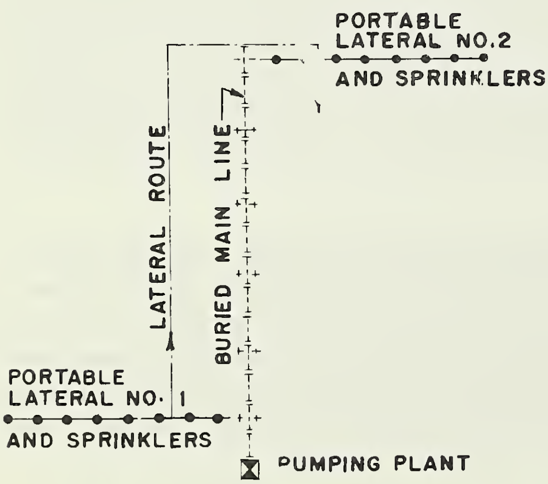
This type is used on permanently irrigated areas and for relatively high-value crops such as orchards, groves, vineyards, berries, and nurseries. These systems are sometimes used in permanent pastures.



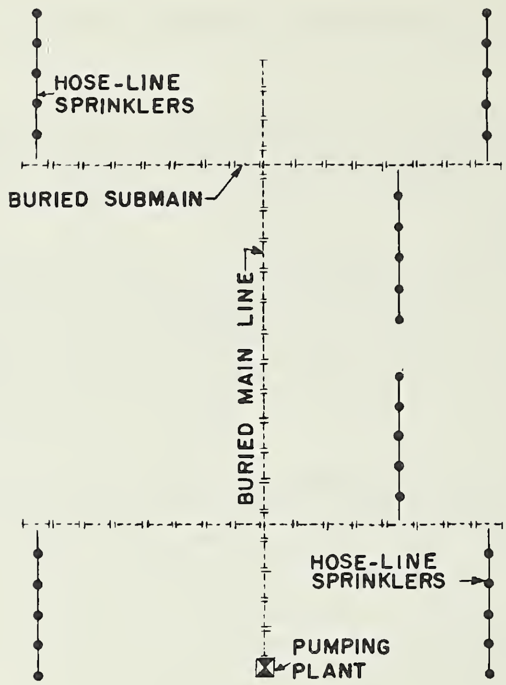
A—Fully portable sprinkler system with portable lateral and movable pumping plant.



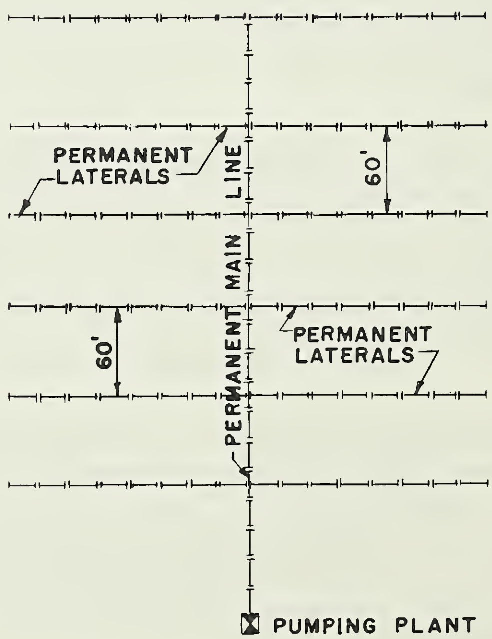
B—Portable laterals and main lines with stationary pumping plant.



C—Portable laterals, permanent buried main line, and stationary pumping plant.



D—Permanent mains and submains with portable hose lines.



E—Permanent main lines and laterals with movable or permanent sprinklers and quick-coupled riser pipes.

Figure 11-8.--General types of revolving sprinkler systems.

The purposes of such systems are to reduce labor costs and eliminate having to move lateral lines especially where tree foliage is heavy. Fully permanent systems are not numerous, however, because of the relatively high installation costs even though, in many cases, these costs would be more than offset by savings in labor costs. The most commonly used materials for buried pipe are asbestos-cement, concrete pressure pipe, and coated steel. In recent years plastic, fiber glass, and aluminum alloy pipe designed for underground use have been successful.

Perforated-Pipe Systems. Perforated-pipe systems may be of the fully portable, semiportable, or semipermanent type. Figure 11-8 A, B, and C can serve to illustrate these systems if perforated pipelines are substituted for the sprinkler lines shown.

They are adapted to the same uses as revolving sprinkler systems except that they are restricted to soils with relatively high intake rates and to crops with foliage that does not adversely affect the distribution pattern.

System-Layout Considerations

Often the layout of a system will be simple, as in the case of small regularly shaped areas. On the other hand, large odd-shaped tracts with broken topography may present a full-scale complex engineering problem requiring alternate layouts and careful pipe-size analyses. The following paragraphs discuss the most important points that must be considered in planning a system layout and the general rules to follow. These rules provide only general guidance to the planner. In the more complex layouts, he may need to exercise considerable judgment.

Number of Sprinklers Operated. A system layout must provide for simultaneous operation of the average number of sprinklers that will satisfy the required system capacity when operated at design pressure. This average number is computed as follows:

$$\text{Number} = \frac{Q(\text{Total system capacity})}{q(\text{Design sprinkler discharge})}$$

The variation in the number of sprinklers operated from time to time during an irrigation should be kept to a minimum to facilitate lateral routing and to maintain a near constant load on the pumping plant. There need be no variation in a rectangular area and, for this reason, farmers should be encouraged to relocate fences, drainage ditches, roads, and other field boundaries, where practicable, to obtain a rectangular area. On odd-shaped fields it is sometimes necessary to operate less than the average required number of sprinklers for one or more lateral settings. In these cases the engine is throttled down to reduce the discharge. Where two or more laterals, each containing different numbers of sprinklers, are operating simultaneously, valves in the lateral lines must be used to control the pressure at the sprinklers. For many odd-shaped tracts, the number of sprinklers will exceed the theoretical average

number computed as already shown, and allowance must be made for extra equipment to service parts of the tract most distant from its center.

Where the design area is subdivided, the number of sprinklers required for each subdivision must be computed separately.

Number of Lateral Settings. The number of settings required for each lateral (operating simultaneously with others where more than one is involved) depends on the number of allowable sets per day and the maximum number of days allowed for completing one irrigation during the peak-use period. The required number of settings per lateral must not exceed the product of these two factors.

If the system layout provides for at least the theoretical number of sprinklers required, then the number of settings required per lateral will not exceed this allowable limit. Long, narrow, or irregular-shaped parts of a tract, however, may require additional lateral settings. Thus more equipment is necessary if these areas are to be served within the allowable time period.

Lateral-Line Layout. To obtain near-uniform application of water throughout the length of a lateral line, the line must be so located and must be of a pipe size and length that will result in a minimum variation in the discharge of individual sprinklers along the line. Since this variation in discharge should not exceed 10 percent, lateral lines must be located and pipe sizes selected so that the total losses in the line, due to both friction head and static head, will not exceed 20 percent of the design operating pressure for the sprinklers.

To meet this pressure-variation criteria, it is usually necessary to lay lateral lines across predominant land slopes.

Laid on level land or on the contour, a lateral line of a given pipe size with a fixed average sprinkler-discharge rate will thus be limited only to that length in which 20 percent of the sprinkler operating pressure is lost due to friction.

Running lateral lines uphill should be avoided where possible. Where they must be used, they need to be materially shortened. Such a lateral of a given pipe size and fixed sprinkler discharge rate is limited to that length in which the loss due to friction is equal to the difference between 20 percent of the sprinkler operating pressure and the loss due to static head. For example, if the static head caused by the difference in elevation between ends of the lateral line amounts to 12 percent of the operating pressure, then the line is limited to that length in which only 8 percent of the operating pressure is lost due to friction.

Running lateral lines downslope is often a distinct advantage, provided the slope is fairly constant and not too steep. Since, under downslope conditions, the difference in elevation between the two ends of the line

becomes a gain in head rather than a loss, lateral lines may be longer than for lines laid on level ground.

While downslope laterals may permit longer laterals for a given pipe size or smaller pipe for a given length of lateral, such a layout does not usually permit split-line layout and lateral rotation. Thus labor costs may be higher.

Where the slope of the ground along the lateral is about equal to the slope of the friction loss (feet per hundred feet), the pressure along the lateral is nearly constant. When the slope along the lateral increases for successive settings, intermediate control valves may be required to avoid building up excess pressures and exceeding the variation limit.

Lateral lines need to be limited to one or not more than two pipe sizes for simplicity of operation. The trend in recent years has been toward the use of a single pipe size.

Lateral lines should be located at right angles to the prevailing wind direction where possible.

Where lateral pipelines are to remain in a single design area and are not to be moved from field to field, they should be so located with respect to the main line that they can be rotated around the main with a minimum of hauling of pipe back to the starting point for the next irrigation (fig. 11-8, C).

Farming operations and row directions often influence the layout of lateral lines. Sprinkling of contoured row crops presents special problems such as (1) difficulty in placing and moving lateral lines, and (2) difficulty in obtaining uniform coverage.

Where the land is terraced and the topography broken, curves in the alinement of the rows may be sharper than can be turned with the limited deflection angle of the coupling devices on portable irrigation pipe. This difficulty may be overcome in several ways: Soil profiles permitting, land grading may be used to improve terrace and row alinement. Short lengths of flexible hose may be used in the line at the sharpest bends. Some growers prefer to run the laterals parallel and downhill on a slope somewhat steeper than the grade of the terraces even though both rows and terraces must be crossed by the pipelines. In such cases, it is customary to remove or leave out several plants in each row at points crossed by the lateral lines.

Where sloping land is terraced and the slopes are not uniform, lateral lines laid between crop rows will not be parallel. Thus the lateral spacing (S_m) will be variable between two adjacent lines. This variation adversely affects the uniformity of application and the efficiency of water use. Where topography permits their use, parallel terraces will help to overcome this problem.

Stripcropping is a conservation practice that has been used effectively in overcoming some of the difficulties arising from sprinkler irrigation of contoured row crops. Row crops are planted in strips equal in width to the lateral spacing (S_m) alternating with strips of hay crops. The hay strips are equal in width to the lateral spacing at the main line point of beginning but may vary considerably in width at points distant from the main line. Lateral lines are laid on the contour along the edges of the row crop strips as shown in fig. 11-9, A. In this method the hay crop as well as the row crop is to be irrigated. Advantages of this procedure are (1) uniformity of coverage on the row-crop strips, and (2) the relative ease of moving the pipe on firmer footing and outside the areas of tall crops. Disadvantages are (1) the oftentimes poor uniformity of coverage on the secondary hay crop, and (2) the necessity for carefully laying out the strips before planting each crop.

When it is not desired to irrigate the hay crop, part-circle sprinklers may be used to irrigate the row crop alone. Another way when it is not desired to irrigate the hay crop is to plant the row crop in wider strips equal in width to some multiple of the lateral spacing (S_m). The laterals are operated entirely within the row-crop strips as shown in figure 11-9, B. A disadvantage is in having to move the pipe when the upper part of the soil is saturated.

Perforated pipe laterals may be used when irrigating low-growing crops such as small vegetables. In such cases, lines are laid on the contour between crop rows.

Main-Line Layout. Main lines, or submains where used, should usually be up and down predominant land slopes. Where laterals are downslope, the main line will often be located along a ridge with laterals sloping downward from each side.

Changes in pipe sizes should be made along the main line for pressure control and to maintain a reasonably balanced load on the pumping plant insofar as possible.

Main lines should be located, where possible, so that laterals can be rotated in a split-line operation, thereby minimizing the labor for hauling lateral pipe back to the starting point. It should be pointed out, however, that the farmers' planting, cultural, and harvesting operations do not always permit a split-line operation. An example would be harvesting flue-cured tobacco over a period of several weeks while irrigation is still in progress. Water is usually applied to a part of the field immediately following a priming (removing ripened leaves from the stalk), and most growers object to priming in several parts of the field simultaneously as would be necessary to stay ahead of the lateral moves in a split-line operation.

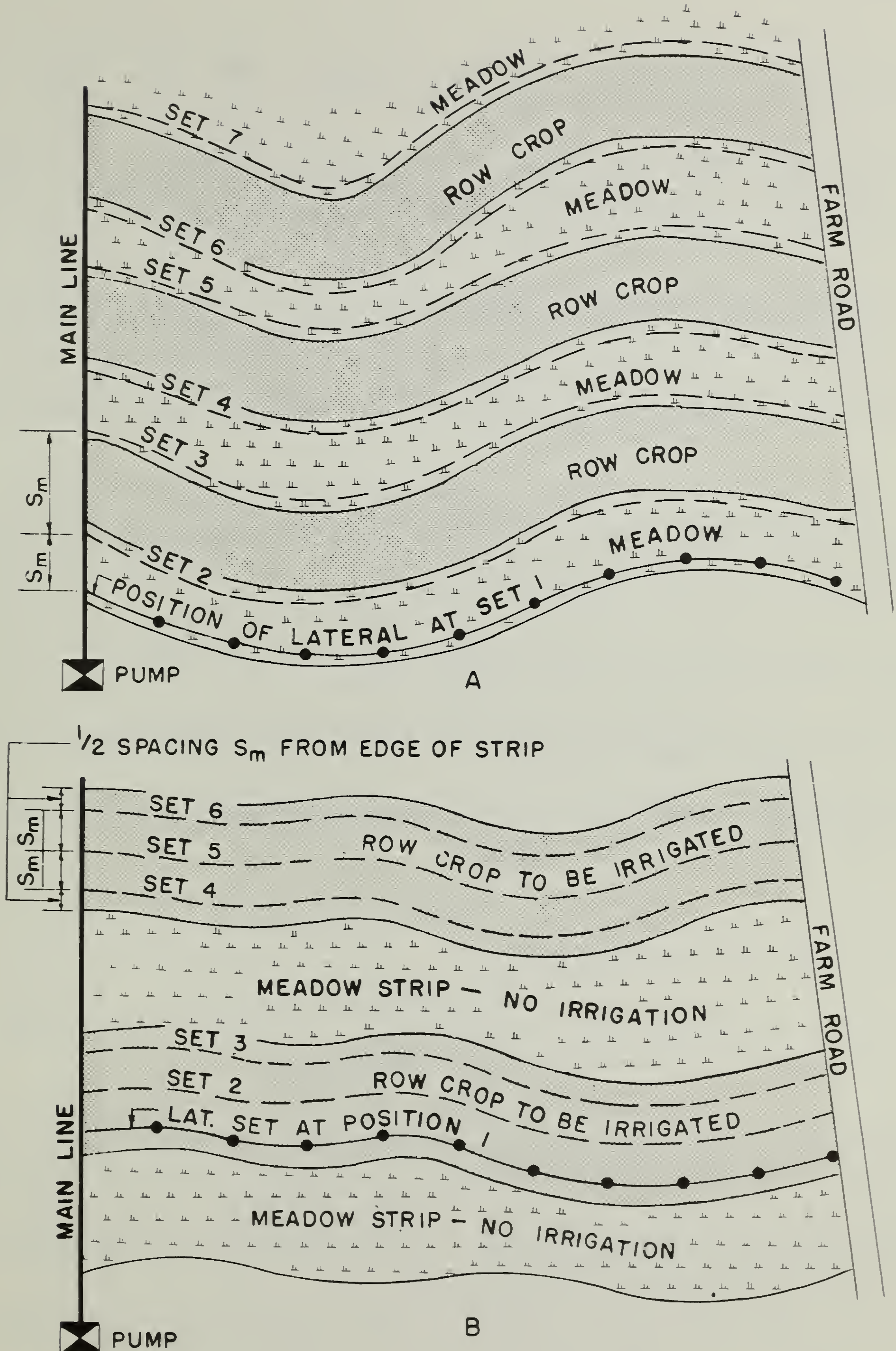


Figure 11-9.--Typical sprinkler layouts on stripcropped areas.

Figure 11-8, C illustrates a typical split-line layout using two laterals. Others may require more laterals.

Effect of Topography. As noted in the discussion of the layout of lateral lines and main lines, topography considerably affects the layout of both. Figure 11-10 illustrates several typical topographic conditions and the effect each will have on the layout of a sprinkler system.

Location of Water Source and Pumping Plant. Where a choice in location of the water-supply source is to be had, the source should be as near as possible to the center of the design area. This results in the least cost for main-line pipe and minimum pumping costs. A choice of location of the water supply is usually possible only when a well is the source.

Where the water source is fixed, a choice in location of the pumping plant is often possible. If so, the pumping plant should be located at a centralized point for delivery to all parts of the design area for the reasons already mentioned. Figure 11-7 illustrates this condition where the choice of pump locations are between points A and F.

For location A, line BC will carry water for 30 acres; while with the pump at F, BC would carry water for 40 acres.

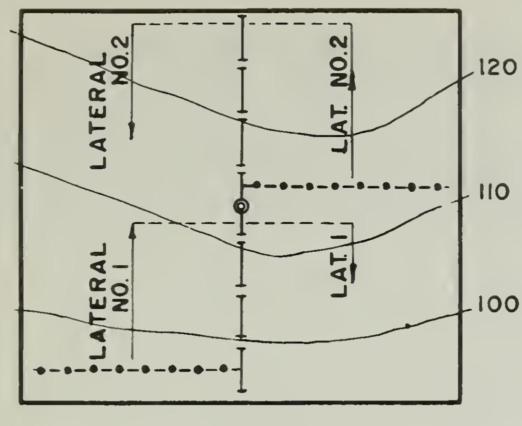
Line CF would carry water for 72 acres with the pump at F, but only for 15 acres with the pump at A.

In this example, pump location A will provide the least cost of main-line pipe.

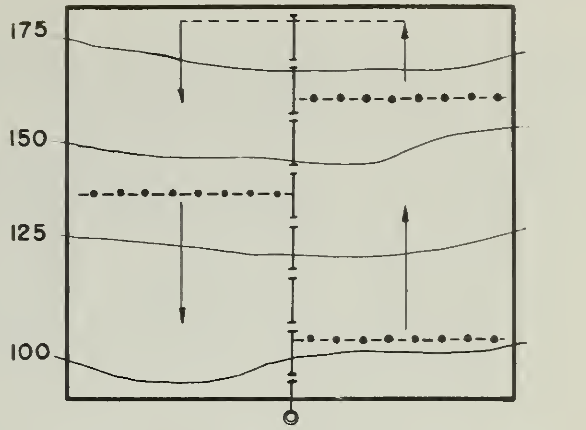
On flat or gentle sloping lands where water is to be pumped from gravity ditches, main-line cost would be least if the water is run in the ditch to the center of the design area.

On steeper lands, where water and pressure are obtained from a gravity line above the design area, cost is least if the gravity line enters the design area at the center of the top boundary.

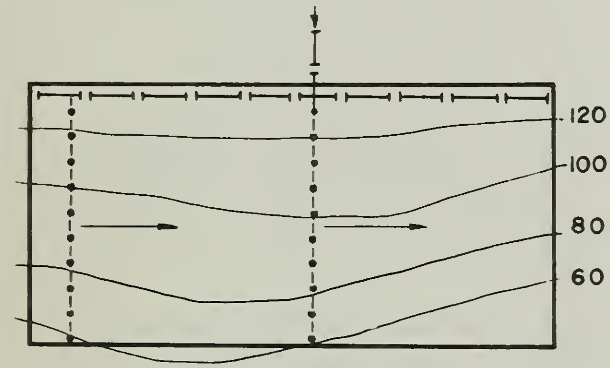
Booster Pumps. Booster pumps should be considered for small parts of the design area to avoid carrying high pressures from the main pumping plant for small fractions of the total discharge. Booster pumps are sometimes used where the static head is so great that two pumps rather than a single unit prove more economical. A careful analysis of pumping costs is required in such cases. Further discussion of booster pumps appears in chapter 8, Irrigation Pumping Plants.



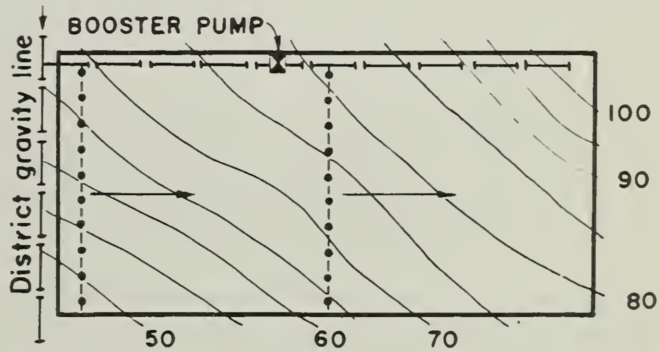
A-Layout on moderate, uniform slopes with water supply at center.



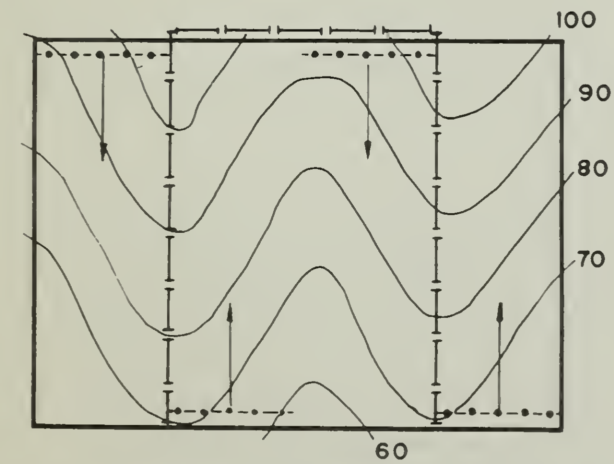
B-Layout illustrating use of odd number of laterals to provide required number of operating sprinklers.



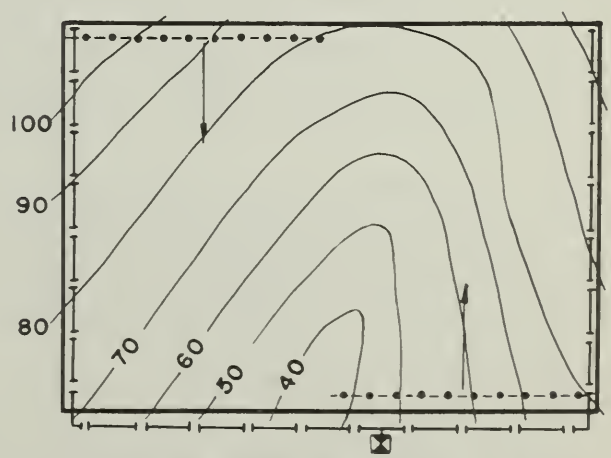
C-Layout with gravity pressure where pressure gain approximates friction loss and allows running lateral downhill.



D-Layout illustrating area where laterals have to be laid downslope to avoid wide pressure variation caused by running laterals upslope.



E-Layout with two main lines on ridges to avoid running laterals uphill.



F-Layout with two main lines on the sides of the area to avoid running the laterals uphill.

Figure 11-10.--Layouts of sprinkler systems showing effects of topography.

Adjustments to Meet Layout Conditions. After completing the layout of main lines and laterals usually it is necessary to make some adjustment in one or more of the following:

Number of sprinklers operating.
Water-application rate.
Sprinkler discharge.
Spacing of sprinklers.
Operating time per day.
Total operating time per irrigation.
Total capacity.

As the designer gains experience, he can forsee these adjustments before making the layout. On regular shaped tracts, the layout can be determined ahead of step 5 (Planning Procedure) and the subsequent steps developed on the basis of fixed layout requirements.

Factors adjusted will depend on what other factors are fixed.

The water-application rate can be adjusted according to the flexibility in time allowed for applying the required amount of water, but this is limited by the maximum and minimum water-application rates as determined by the water-intake rate of the soil.

Since water-application rate is a function of sprinkler discharge and spacing, the discharge can be modified only to the extent that average application rate or spacing, or both, can be modified.

Adjustment of spacing can be made within limits in order to maintain a fixed water-application rate. Change in spacing on the lateral can be made in 10-foot intervals to revise the number of operating sprinklers for a fixed length of lateral.

Adjustments in water-application rate to fit the requirements of a good layout must be compensated for by modifying the operating period to fit the gross amount of water to be applied.

Before the layout is made, the number of days and operating hours during the day are assumed in computing the total capacity of the system. The total time of operation may be reduced if the daily operating time is increased or if the number of settings for individual laterals is less than the product of the number of settings per day and the number of days allowed.

The system capacity is the product of the maximum number of operating sprinklers and the design sprinkler discharge.

$$Q = N_{max} \times q$$

The system capacity also varies inversely as the total operation time for an irrigation period varies.

$$Q = \frac{453\ Ad}{FH}$$

Therefore, the final adjustment is to compute the total system capacity needed to satisfy maximum demands. Sample calculation 11-4 illustrates the problem of adjusting to layout requirements.

Sample calculation 11-4.--Adjusting operating conditions to layout requirements

---

Given:

42.3-acre tract 1280 by 1440 feet.
Application of 2.6 acre-inches per acre at each irrigation.
Irrigation frequency: 10 days at peak-use period.
Optimum application rate: 0.40 inch per hour for 6-1/2 hours.
Capacity requirements of system: 383 gallons per minute (2 sets per day).
Type of sprinkler--dual-nozzle, intermediate-pressure range.
Sprinkler spacing: 60 by 80 feet.
Sprinkler discharge: 20.0 gallons per minute for application of 0.40 inch per hour.
Number of sprinklers required: $\frac{383 \text{ gallons per minute}}{20.0 \text{ gallons per minute}} = 19.$

Layout:

Fix layout with one main line, 1280 feet long, through center of tract and two laterals, each 720 feet long, operated in a split-line manner.
With a 60-foot spacing on the laterals, the number of sprinklers required: $\frac{2 \times 720}{60} = 24.$
Number of settings for each lateral: $\frac{1280 \text{ feet}}{80 \text{ feet}}$ or 16 sets per irrigation. Since labor is not available for nightwork, only two settings per day of 6-1/2 hours each are contemplated.
Time required to complete 1 irrigation: $\frac{16}{2} = 8$ days.

Adjustments to Meet Layout Requirements:

Since number of sprinklers to meet layout requirements are more than number required, as computed under number of sprinklers required and since the time required to complete one irrigation is less than the irrigation frequency, adjust as follows:
Maintain optimum application rate and setting time at 0.40 inch per hour for 6-1/2 hours.
Increase number of sprinklers operating from 19 to 24 with spacing and discharge unchanged.
The required system capacity will have to be adjusted from 383 gallons per minute to 24x20.0 or 480 gallons per minute.

Lateral-Line Design

Lateral line pipe sizes will be so chosen that the total pressure variation in the line, due both to friction head and static head (if any), does not exceed 20 percent of the design operating pressure of the sprinklers.

Friction Losses in Laterals. A flow of water through the entire length of a pipeline of given diameter and length will obviously cause more friction loss than one through a line with a number of equally spaced outlets. The reason for this is the reduction in flow each time an outlet is passed.

The method developed by Christiansen[1] for computing pressure losses in multiple-outlet pipelines has been widely accepted and is used here. It involves first computing the friction loss in the line without multiple outlets by the use of Scobey's[2] formula and then applying a factor (F) based on the number of outlets (sprinklers) in the line (N). Scobey's formula is

$$H_f = \frac{K_s \times L \times V^{1.9}}{1000D^{1.1}}$$

where H_f = friction loss in the line in feet
K_s = coefficient of retardation based solely on the character and condition of the pipe material
L = length of the line in feet
V = velocity of flow in the line in feet per second
D = diameter of the pipe in feet

For the convenience of the planner, table 11-3 has been computed by this formula using K_s values as shown.

The empirical equation for computing the factor (F) for multiple outlets is

$$F = \frac{1}{m+1} + \frac{1}{2N} + \frac{\sqrt{m-1}}{6N^2}$$

where m = 1.9, velocity exponent of Scobey's formula

N = number of outlets in the line.

Table 11-4 shows values of this factor for different numbers of outlets.

As an example, the calculation for the head loss due to friction (H_f) in 1320 feet of 6-inch aluminum pipe with couplers, made up of 20-foot sections, having 22 sprinklers spaced 60 feet apart each discharging 25 gallons per minute for a total of 550 gallons per minute is

$$H_f = \frac{1320}{100} \times 2.52 \text{ (table 11-3)} \times 1.07 \text{ (footnote table 11-3)} \times .368$$
$$\text{(table 11-4)} = 13.10 \text{ feet} = 5.67 \text{ pounds per square inch}$$

[1] Christiansen, J. E. Irrigation by Sprinkling. Univ. Calif. Bul. 670. 1942.

[2] Scobey, F. C. The Flow of Water in Riveted Steel and Analogous Pipes. U.S. Dept. Agr. Tech. Bul. 150. 1930.

Table 11-3.--Friction loss in feet per 100 feet in lateral lines of portable aluminum pipe with couplings

(Based on Scobey's formula and 30-foot pipe lengths)[1]

Flow (gallons per minute)	2-inch[2] K_s = .34	3-inch[2] K_s = .33	4-inch[2] K_s = .32	5-inch[2] K_s = .32	6-inch[2] K_s = .32
40	4.49	0.565	0.130		
50	6.85	.858	.198		
60	9.67	1.21	.280		
70	12.9	1.63	.376	0.122	
80	16.7	2.10	.484	.157	
90	20.8	2.63	.605	.196	
100	25.4	3.20	.738	.240	0.099
120		4.54	1.04	.339	.140
140		6.09	1.40	.454	.188
160		7.85	1.80	.590	.242
180		9.82	2.26	.733	.302
200		12.0	2.76	.896	.370
220		14.4	3.30	1.07	.443
240		16.9	3.90	1.26	.522
260		19.7	4.54	1.47	.608
280		22.8	5.22	1.70	.700
300		25.9	5.96	1.93	.798
320		29.3	6.74	2.18	.904
340		32.8	7.56	2.45	1.02
360		36.6	8.40	2.74	1.13
380		40.6	9.36	3.03	1.26
400		44.7	10.3	3.34	1.38
420			11.3	3.66	1.51
440			12.3	4.00	1.66
460			13.4	4.35	1.80
480			14.6	4.72	1.95
500			15.8	5.10	2.12
550			18.9	6.12	2.52
600			22.2	7.22	2.98
650			25.9	8.40	3.46
700			29.8	9.68	3.99
750			33.8	11.0	4.54
800				12.5	5.15
850				14.0	5.78
900				15.6	6.44
950				17.3	7.14
1000				19.0	7.86

[1] For 20-ft. pipe lenths, increase values in the table by 7.0 percent. For 40-ft. lengths, decrease values by 3.0 percent.
[2] Outside diameter.

Table 11-4.--Factor (F) for computing friction loss in a line with multiple outlets

Outlets (Number)	Value of F	Outlets (Number)	Value of F
1................	1.000	16	0.377
2................	.634	17	.375
3................	.528	18	.373
4................	.480	19	.372
5................	.451	20	.370
6................	.433	21	.369
7................	.419	22	.368
8................	.410	23	.367
9................	.402	24	.366
10...............	.396	25	.365
11...............	.392	26	.364
12...............	.388	27	.364
13...............	.384	28	.363
14...............	.381	29	.363
15...............	.379	30	.362

Laterals on Level Ground. In this case, the allowable pressure loss due to friction in the lateral line will be equal to 20 percent of the average design operating pressure for the sprinklers (P_a).

To determine the size of pipe required, first divide 20 percent of P_a (in feet) by the product of the length of the lateral line in 100-foot stations and the appropriate F factor taken from table 11-4. This calculation will result in the maximum allowable loss in feet per 100 feet if the total lateral discharge were carried through the entire line.

$$\text{Allowable loss per 100 feet} = \frac{.20\ P_a \times 2.31}{L/100 \times F}$$

This calculation is based on 30-foot pipe sections. If 20-foot sections are used, divide the allowable loss by 1.07; for 40-foot sections, by 0.97.

Next enter the gallons-per-minute column in table 11-3 at the line corresponding to the total lateral discharge and, moving along that line to the right, find the pipe-size column which contains a value just equal to or less than the computed allowable loss per 100 feet of line. This is the pipe size required. Reverse the procedure to determine the actual pressure loss due to friction (P_f).

To determine the pressure requirements at the main line (P_m) the pressure required to lift the water in the sprinkler riser pipe (P_r) must be considered. P_r is equal to the height of the riser pipes in feet divided by 2.31.

Then

$$P_m = P_a + 3/4\ P_f + P_r$$

The factor (3/4) is used to provide for the average operating pressure (P_a) at the center of the line rather than at the distal end.

Laterals Laid Uphill. In this case, the allowable pressure loss due to friction (P_f) is equal to 20 percent of the average design operating pressure (P_a) minus the pressure required to overcome elevation in the line P_e (fig. 11-11). Thus the allowable $P_f = .20P_a - P_e$.

To determine the size of pipe required and the actual value of P_f, the same procedures described for Lateral Lines on Level Ground is used. The allowable loss expressed in feet per 100 feet is

$$\frac{(.20\ P_a - P_e) \times 2.31}{L/100 \times F}$$

To determine the pressure required at the main line

$$P_m = P_a + 3/4\ (P_f + P_e) + P_r.$$

Sample calculation 11-5 illustrates this problem.

Laterals Laid Downhill. In this case, the allowable pressure loss due to friction (P_f) is equal to 20 percent of the average design operating pressure (P_a) plus the pressure gained by the difference in elevation in the line (fig. 11-12). Thus the allowable $P_f = .20P_a + P_e$.

On steep slopes, it is desirable to reduce pipe sizes and to minimize the pressure variation along the line. Pipe sizes are selected on the basis of friction loss equaling elevation gain or $P_f = P_e$.

To determine the size of pipe required and the actual value of P_f, the same procedure described for Lateral Lines on Level Ground is used. The maximum allowable loss expressed in feet per 100 feet is

$$\frac{(.20\ P_a + P_e) \times 2.31}{L/100 \times F}$$

To determine the pressure required at the main line

$$P_m = P_a + 3/4\ P_f - 3/4\ P_e + P_r$$

Sample calculation 11-6 illustrates this problem.

Laterals--Two Pipe Sizes. Most farmers prefer lateral lines of a single pipe size for convenience. A few want to use two pipe sizes where their use will result in a reduction in initial costs. Laterals containing more than two pipe sizes should never be considered.

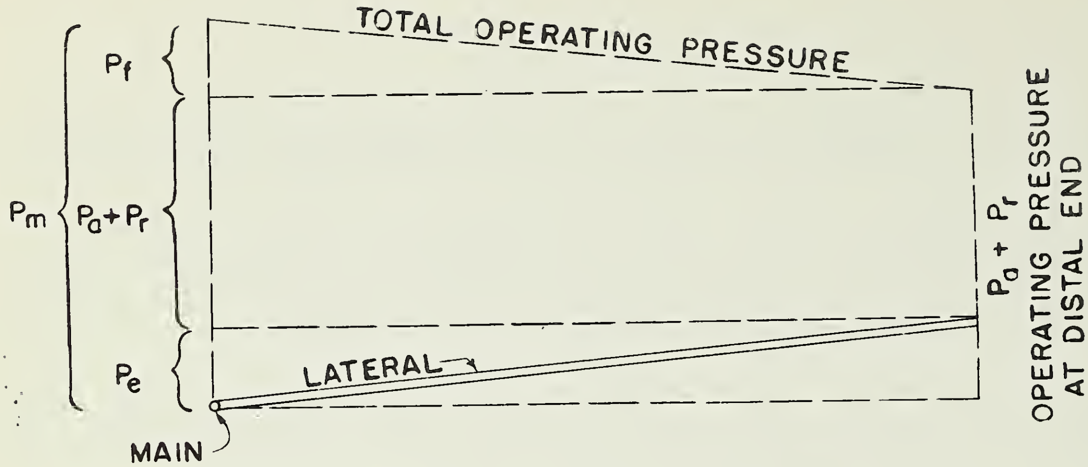


Figure 11-11.--Lateral laid uphill.

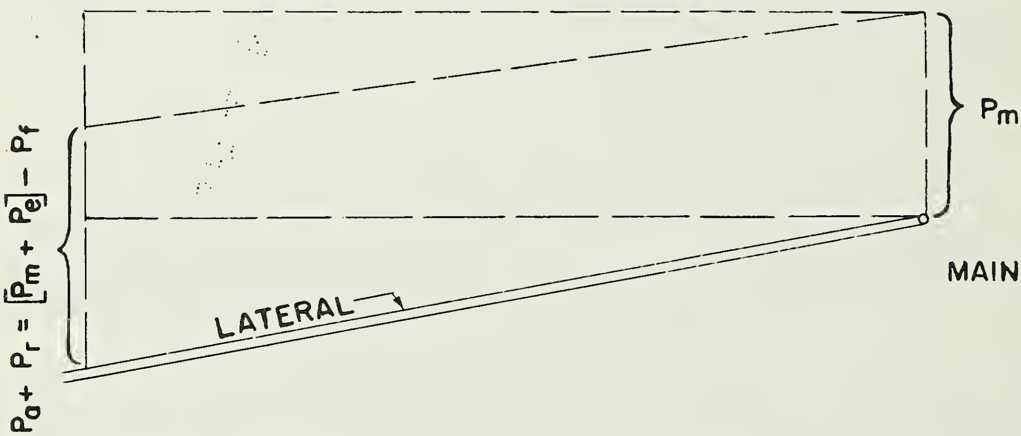


Figure 11-12.--Lateral laid downhill.

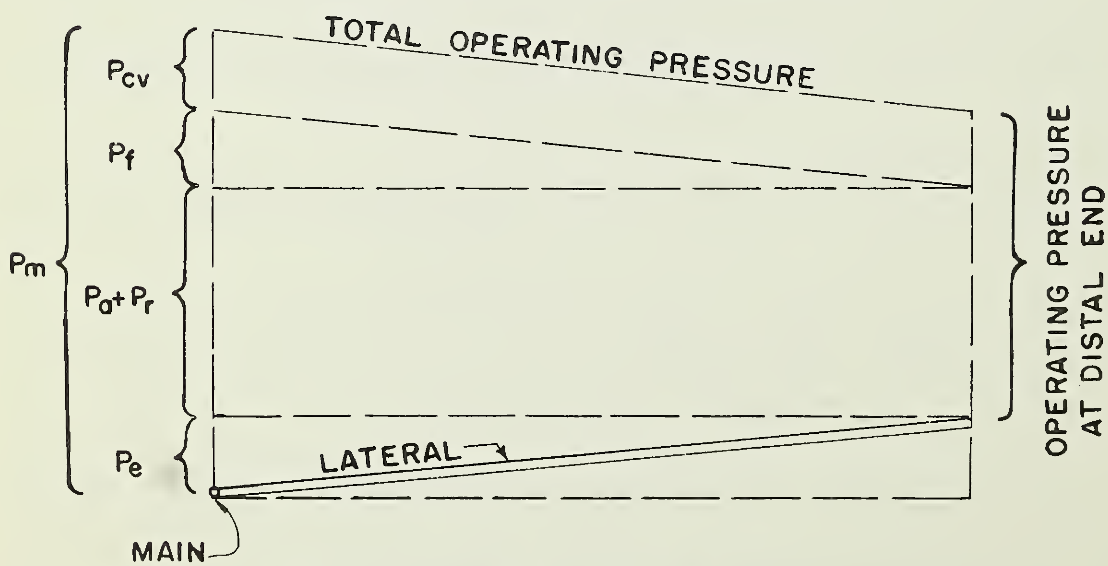
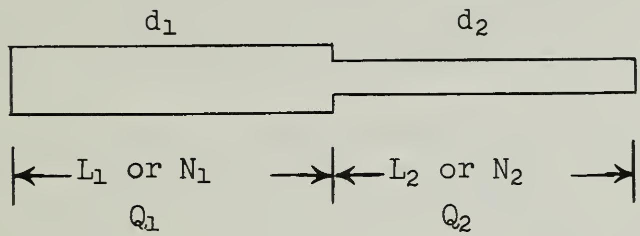


Figure 11-13.--Lateral with flow-control valves.

Tables 11-3 and 11-4 can be used to find the nearest uniform pipe size for a lateral line that will result in a friction loss equal to or less than 0.20 P_a. The tables may also be used to obtain the lengths of each of two pipe sizes on a lateral line. In those few cases where it is desirable to determine losses for specific lengths of each of two pipe sizes, the following procedure may be used



1. Compute the allowable pressure loss due to friction (P_f) for the total length of the line as described.
2. Convert this computed value of P_f to loss in feet per 100 feet of pipe by use of the formula

$$H_f = \frac{P_f \times 2.31}{L/100 \times F}$$

where L = length of the lateral line in feet

F = applicable multiple outlet factor for N_1+N_2 sprinklers taken from table 11-4.

Where other than 30-foot sections of pipe are used, the value of H_f must be corrected as explained in table 11-3.

3. With the total lateral line capacity (Q) and the allowable loss per 100 feet of pipe (H_f) both known, use table 11-3 to find the two sizes required.
4. Determination of the specific lengths of each of the two pipe sizes required is a trial and modification procedure. First estimate lengths L_1 and L_2 and then compute the total pressure loss due to friction for these lengths. Should this loss fall above or below the allowable loss (P_f) different values of L_1 and L_2 are assumed, and the procedure is repeated.
5. Using tables 11-3 and 11-4, find the loss in length (L_2) of pipe diameter (d_2) containing N_2 number of sprinklers and discharging Q_2 gallons per minute.
6. Assume that pipe diameter d_1 extends for the full length of the lateral line, and, by the same procedure, find the loss for length L_1+L_2 containing N_1+N_2 sprinklers and discharging Q_1+Q_2 gallons per minute.
7. Next, find the loss in length L_2 for pipe diameter d_1 containing N_2 number of sprinklers and discharging Q_2 gallons per minute.

8. Add the losses obtained in 5 and 6, and subtract from this total the losses obtained in 7.

$$\Sigma H_f = H_{f_2}(\text{for } d_2) + h_{f_{1+2}}(\text{for } d_1) - H_{f_2} \text{ for } (d_1)$$

9. Sample calculation 11-5 illustrates this problem.

Sample calculation 11-5.--Laterals laid out uphill--two pipe sizes

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Given:

Lateral consisting of 960 feet of portable aluminum irrigation pipe with 24 sprinklers spaced 40 feet apart, discharging at the rate of 12.5 gallons per minute operating at 44 pounds per square inch.
Length of pipe sections: 40 feet.
Lateral capacity: Q = 300 gallons per minute.
Elevation difference to overcome: E = 9.0 feet (uphill).
Height of risers for corn: 8.0 feet.

Find:

Smallest pipe sizes that will limit pressure loss due to both friction and elevation difference to 20 percent of the average operating pressure that the sprinkler discharge was designed.
Pressure requirements at the main line.

Calculation:

Referring to figure 11-11, determine allowable friction loss (P_f) where

P_a = 44 pounds per square inch and $P_e = \dfrac{9.0}{2.31}$ = 3.9 pounds per square inch

$$P_f = .20\, P_a - P_e = .20 \times 44 - 3.9 = 4.9 \text{ pounds per square inch}$$

The allowable loss due to friction expressed in feet per 100 feet is

$$H_f = \frac{P_f \times 2.31}{L/100 \times F} = \frac{4.9 \times 2.31}{9.6 \times .366} = 3.22 \text{ feet per 100 feet}$$

Correcting for the use of 40-foot pipe sections

$$H_f = \frac{3.22}{.97} = 3.32 \text{ feet per 100 feet}$$

Using a lateral capacity (Q) of 300 gallons per minute and an allowable friction loss (H_f) of 3.32 feet per 100 feet, table 11-3 indicates that some 5-inch and some 4-inch pipe will be required.

Assume half or 480 feet of 5-inch pipe and 480 feet of 4-inch. Then

d_1 = 5 inches	d_2 = 4 inches
L_1 = 480 feet	L_2 = 480 feet
N_1 = 12	N_2 = 12
Q_1 = 150 g.p.m.	Q_2 = 150 g.p.m.

Using tables 11-3 and 11-4, find the loss in 480 feet (L_2) of 4-inch (d_2) pipe containing 12 (N_2) sprinklers and discharging 150 (Q_2) gallons per minute.

$$H_{f_2} \text{ (for } d_2) = \frac{4.8 \times 1.60 \times .97 \times .388}{2.31} = 1.25 \text{ pounds per square inch}$$

Assume 5-inch (d_1) diameter for the entire length of the line and find the loss in 960 (N_1+N_2) feet containing 24 (N_1+N_2) sprinklers and discharging 300 (Q_1+Q_2) gallons per minute.

$$H_{f_{1+2}} \text{(for } d_1) = \frac{9.6 \times 1.93 \times .97 \times .366}{2.31} = 2.85 \text{ pounds per square inch}$$

Find the loss in 480 (L_2) feet of 5-inch (d_1) diameter containing 12 (N_2) sprinklers discharging 150 (Q_2) gallons per minute.

$$H_{f_2} \text{ (for } d_1) = \frac{4.8 \times .522 \times .97 \times .388}{2.31} = .41 \text{ pounds per square inch}$$

Then

$$\Sigma H_f = 1.25+2.85-.41 = 3.69 \text{ pounds per square inch}$$

This value is lower than the allowable P_f of 4.9 pounds per square inch. Thus less 5-inch pipe and more 4-inch pipe are indicated.

By assuming 320 feet of 5-inch pipe containing 8 sprinklers and 640 feet of 4-inch pipe containing 16 sprinklers, a repetition of the procedure results in

$$\Sigma H_f = 2.79+2.85-.91 = 4.73 \text{ pounds per square inch (OK)}$$

Pressure requirements at the main line are

$$P_m = P_a + 3/4\ (P_f + P_e) + P_r = 44.0 + 3/4\ (4.7 + 3.9) + \frac{8.0}{2.31}$$
$$= 54.0 \text{ pounds per square inch.}$$

Sample calculation 11-6.--Laterals laid out downslope

Given:

Lateral consisting of 960 feet of portable aluminum irrigation pipe with 24 sprinklers spaced 40 feet apart, discharging at the rate of 12.5 gallons per minute operating at 44 pounds per square inch.

Length of pipe sections to be used: 20 feet.

Lateral capacity: Q = 300 gallons per minute.

Average downhill slope: 3.5 percent or 33.6 feet in total length of the line.

Height of risers for corn = 8.0 feet.

Owner desires one pipe size only.

Find:

Smallest pipe size that will result in an approximate balance between pressure loss due to friction and pressure gain due to elevation.

Pressure requirements at the main line.

Calculation:

Assume the allowable pressure loss due to friction (P_f) to be equal to the pressure gain due to elevation $P_e = \frac{33.6}{2.31} = 14.5$ pounds per square inch.

Converting the allowable friction loss to feet per 100 feet.

$$H_f = \frac{P_f \times 2.31}{L/100\ F} = \frac{14.5 \times 2.31}{9.6 \times .366} = 9.53 \text{ feet per 100 feet.}$$

Correcting allowable loss for use of 20-foot sections.

$$H_f = \frac{9.53}{1.07} = 8.91 \text{ feet per 100 feet.}$$

Using a lateral capacity of 300 gallons per minute, and an allowable loss of 8.91 feet per 100 feet, table 11-3 indicates some 3-inch and some 4-inch pipe will be required. Since the owner wishes to use only one pipe size, use 4-inch. The pressure loss due to friction resulting from the use of 4-inch pipe would be

$$P_f = \frac{9.6 \times 5.96 \times 1.07 \times .366}{2.31} = 9.7 \text{ pounds per square inch.}$$

Percentagewise the pressure variation in the line is

$$\frac{P_e - P_f}{P_a} = \frac{14.5 - 9.7}{44} = 10.9 \text{ percent}$$

If all 3-inch pipe were used, the pressure loss due to friction would be 42.2 pounds per square inch, and the resulting pressure variation would be

$$\frac{P_f - P_e}{P_a} = \frac{42.2 - 14.5}{44} = 63 \text{ percent}$$

This is obviously outside the 20-percent limitation. Thus a line consisting of all 3-inch pipe could not be used.

Pressure requirements at the main line for a 4-inch pipe size are

$$P_m = P_a + 3/4\ P_f - 3/4\ P_e + P_r = 44 + (3/4 \times 9.7) - (3/4 \times 14.5) + \frac{8.0}{2.31} = 43.9 \text{ pounds per square inch}$$

Laterals with Flow-Control Devices. Flow- or pressure-control devices are used in lateral lines where the topography is too broken or too steep to permit the pressure variation in the line to be controlled within the 20-percent limit by the selection of practical pipe sizes. These devices are valves placed between the lateral line and the sprinkler head at each sprinkler outlet; they are designed to provide equal pressure and equal discharge at all sprinklers.

The pressure that must be provided at the distal end of the line will be the pressure required to operate the sprinklers (P_a) plus that required to overcome the height of the riser pipe (P_r) plus that required to overcome friction loss in the control valves (P_{cv}) (fig. 11-13). Since the valves control the discharge of the sprinklers the selection of lateral pipe sizes is not a problem of maintaining a specified pressure variation between sprinklers but one that is largely economics. The allowable pressure loss due to friction (P_f) should be that which will result in the lowest annual pumping cost. For most conditions (P_f) may be assumed to be about 0.20 P_a.

The pressure requirements at the main line

$$P_m = P_a + P_f + P_e + P_r + P_{cv}$$

The manufacturers of these valves will have to furnish data on the pressure losses for different discharges and pressure reductions (fig. 11-14). Sample calculation 11-7 illustrates the procedure involved in the design of a lateral line containing these valves.

Sample calculation 11-7.--Laterals with pressure-control valves

Given:

A lateral line, 1320 feet long, running up and down slopes on broken topography, the highest point on the line being 33 feet above the junction of the lateral with the main. The lateral line contains 22 sprinklers, 1/4x7/32 inch, discharging 22.5 gallons per minute under an operating pressure of 50.0 pounds per square inch.

Length of pipe sections used: 30 feet.

Risers for corn: 8.0 feet.

Find:

Pipe size required and the pressure requirements at the main line.

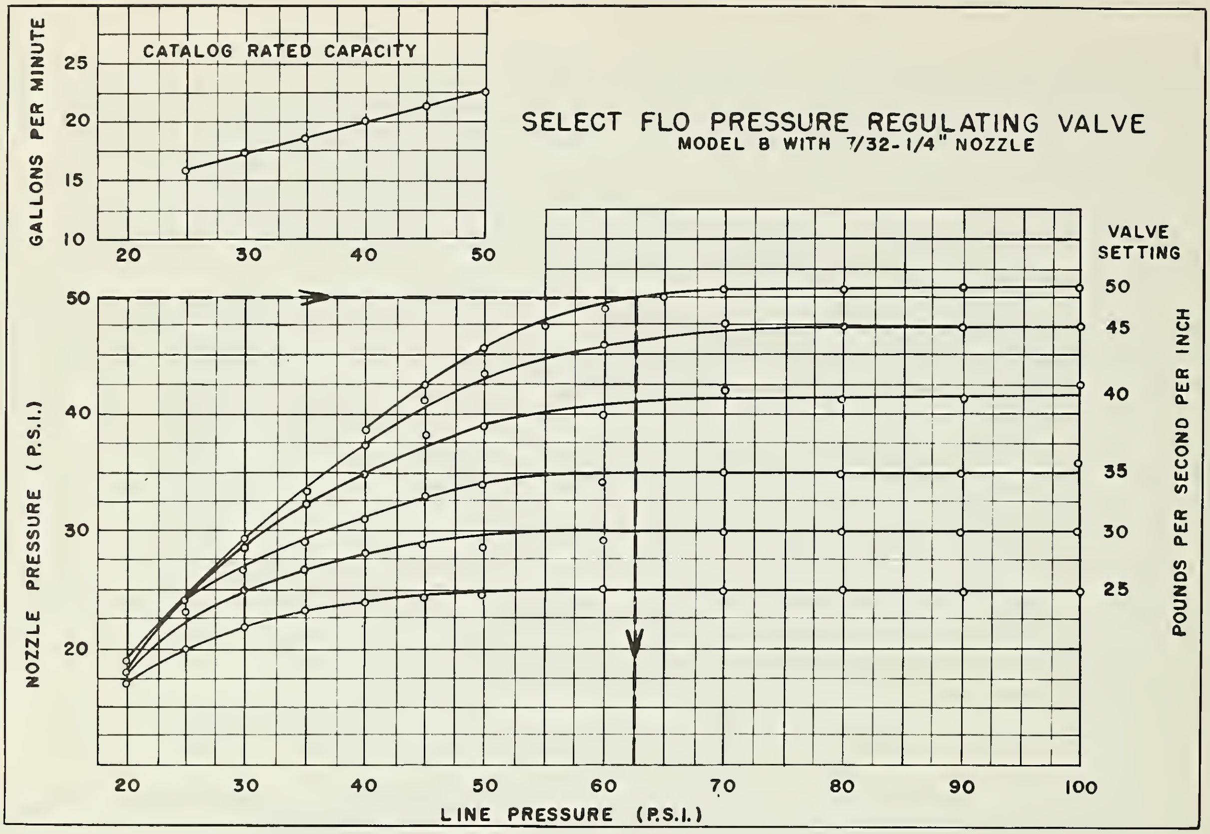
Calculation:

Allowable loss due to friction: .20 P_a = .20 x 50.0 = 10.0 pounds per square inch.

Pressure required to overcome elevation is

$$P_e = \frac{33}{2.31} = 14.3 \text{ pounds per square inch}$$

Since the pressure loss required to overcome elevation is greater than the allowable pressure loss due to friction, flow- or pressure-control valves will be required to equalize pressure along the line. From tables 11-3 and 11-4, it is determined that a 5-inch line will satisfy the



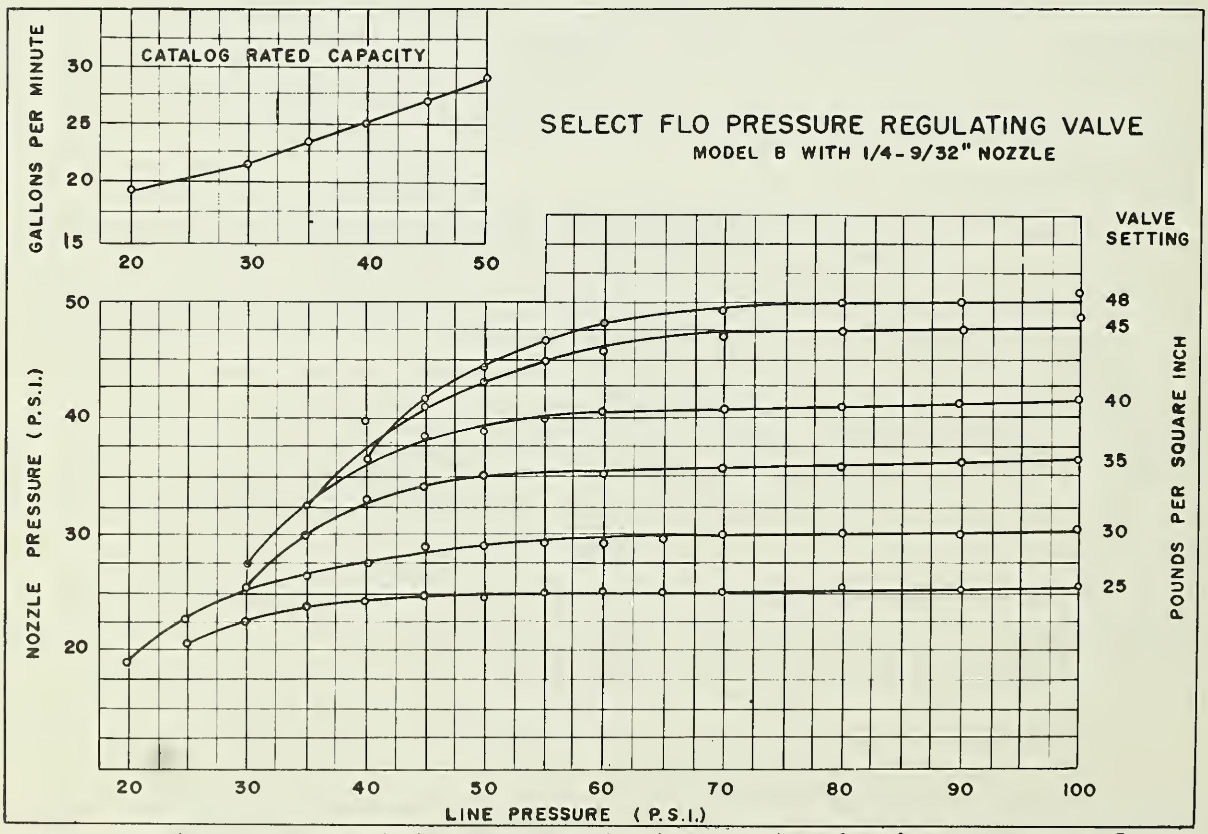


Figure 11-14.--Oregon State College test results showing pressure losses in flow-control valves. A, Tested with Select Flo regulating valve model B with 7/32 - 1/4-inch nozzle; B, tested with Select Flo regulating valve model B with 1/4 - 9/32-inch nozzle.

allowable pressure loss due to friction sufficiently close for all practical purposes.

$$P_f = \frac{13.2 \times 5.00 \times .368}{2.31} = 10.5 \text{ pounds per square inch}$$

Using figure 11-14, A, enter the chart from the left at the design nozzle operating pressure P_a = 50.0 pounds per square inch. Follow the 50.0 line horizontally to the right until the 50.0 valve setting curve is intersected. Read the line pressure on the scale below to be 63 pounds per square inch. Thus the pressure loss in the control valves (P_{cv}) is 63-50 or 13 pounds per square inch.

Pressure requirements at the main line are

$$P_m = P_a + P_f + P_e + P_r + P_{cv} = 50.0 + 10.5 + 14.3 + \frac{8.0}{2.31} + 13.0$$
$$= 91.3 \text{ pounds per square inch}$$

Hose-Line Design. Hose lines for undertree sprinkling is a special problem. In 100-foot hose lines, four to five sprinklers are common. To obtain the friction loss for hose line with sprinklers, multiply the values given in table 11-5 by the factors given in table 11-4.

Table 11-5.--Approximate friction loss in garden hose and garden hydrants[1]

Total flow (gallons per minute)	Friction loss per square inch, for[2]--			
	100 feet of 3/4-inch hose	100 feet of 1-inch hose	3/4-inch garden hydrant	1-inch garden hydrant
	Pounds	*Pounds*	*Pounds*	*Pounds*
5.........	6.8	1.6	0.3	0.1
6.........	9.6	2.0	.4	.2
7.........	12.8	2.8	.6	.2
8.........	16.0	3.6	.8	.3
9.........	20.0	4.4	1.0	.4
10.........	24.4	5.6	1.2	.5
12.........	34.0	8.0	1.7	.7
14.........	45.2	10.4	2.4	.9
16.........	58.0	12.2	3.1	1.2
18.........	72.0	16.4	3.9	1.5
20.........	88.0	20.0	4.8	1.9
22.........	---	24.0	5.8	2.3
24.........	---	28.0	6.9	2.7
26.........	---	32.4	8.0	3.2
28.........	---	37.2	9.2	3.7
30.........	---	42.0	10.6	4.3

[1] Friction losses in hose and valves vary widely with different makes of equipment. These values, based on tests at Davis, should be used only as a guide in determining the size required.

[2] To convert pressure in pounds per square inch to head in feet, multiply by 2.31.

Perforated-Pipe Laterals. Since perforated-pipe laterals are lines with equally spaced multiple outlets, the same general principles applicable to the design of revolving sprinkler laterals are applicable to perforated pipe laterals. However, there are more restrictions on the design of perforated pipe laterals. Because of their low operating pressure, lateral lines must be laid very nearly on the level if pressure variation along the line is to be kept within acceptable limits. Pressure-control valves cannot be used for this purpose. Only one pipe size is used.

Perforated pipe is readily available for only four rates of application--1/2 inch, 1 inch, 1-1/2 inch, and 2 inches per hour--though the manufacturers will perforate the pipe for higher rates on a custom basis. This limit in application rates materially reduces flexibility in design.

The manufacturers of perforated pipe have simplified the design of lateral lines by furnishing performance tables for each combination of pipe size and application rate. The length of the line being known, it is easy to read the discharge, spread, and operating pressure from the tables. Table 11-6 is an example. The designer should request such tables from the manufacturer when confronted with perforated-pipe-design problems.

By way of illustrating the use of such a table, assume lateral lines 750 feet in length, spaced 40 feet apart, applying water at the rate of 1.0 inch per hour. Since lateral lengths of 750 feet are included in table 11-6 covering 5-inch pipe and an application rate of 1.0 inch per hour, this size pipe may be used. Enter the 750-foot length column and follow the column downward until a spread of 42 feet is reached. A spread 2 feet greater than the lateral spacing is customarily used to provide a 1-foot overlap between laterals to prevent dry areas. At a 42-foot spread it will be noted that the lateral discharge is 364 gallons per minute. Following a horizontal line to the left, the inlet pressure or pressure required at the main line (P_m) may be read direct to be 15.0 pounds per square inch.

Main-Line Design

Main lines for sprinkler systems vary from short portable feeder lines to intricate networks of buried mains and submains for large systems. The principal function of main lines and submains is to convey the quantities of water required to all parts of the design area at the pressure required to operate all lateral lines under maximum conditions. The principal design problem is the selection of pipe sizes that will accomplish this function economically. For the purposes here, the line running from the water source to the design area, usually called the supply line, will be treated as a part of the main line.

The design of main lines or submains requires an analysis of the entire system to determine maximum requirements for capacity and pressure.

Table 11-6.--Typical performance table for perforated pipelines[1]

Inlet pressure		5-inch diameter--application rate = 1.0 inch per hour																		
		Length of line (feet)-																		
		50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950
6	G.p.m.	16	32	48	64	80	96	112	127	142	157	172	187	202	217	231	245	259	273	286
	Spread	30	30	30	30	30	30	30	29	29	29	29	28	28	28	27	27	26	26	25
7	G.p.m.	17	34	51	68	85	102	119	136	153	170	186	202	218	234	250	265	280	295	309
	Spread	33	33	33	33	32	32	32	32	32	32	31	31	31	30	30	29	29	28	27
8	G.p.m.	18	36	54	72	90	108	126	144	162	180	198	215	232	249	266	282	298	314	330
	Spread	35	35	35	35	35	35	35	34	34	34	34	33	33	33	32	32	31	30	30
9	G.p.m.	19	38	57	76	95	114	133	152	171	190	209	227	245	263	281	298	315	332	348
	Spread	37	37	37	37	37	37	37	37	36	36	36	35	35	35	34	34	33	32	32
10	G.p.m.	20	40	60	80	100	120	140	160	180	200	220	239	258	277	296	314	332	350	367
	Spread	39	39	39	39	39	39	38	38	38	38	37	37	37	36	36	35	35	34	33
11	G.p.m.	21	42	63	84	105	126	147	168	189	210	231	251	271	291	311	330	349	368	386
	Spread	40	40	40	40	40	40	40	40	40	39	39	39	38	38	37	37	36	36	35
12	G.p.m.	22	44	66	88	110	132	154	176	198	220	241	262	283	304	324	344	364	383	402
	Spread	41	41	41	41	41	41	41	41	41	41	40	40	40	39	39	39	38	37	37
13	G.p.m.	23	46	69	92	115	138	161	184	207	230	252	274	296	318	339	360	381	401	421
	Spread	43	43	43	43	43	43	42	42	42	42	42	41	41	41	40	40	39	39	38
14	G.p.m.	24	48	72	96	120	144	168	192	216	239	262	285	308	330	352	374	395	416	437
	Spread	44	44	44	44	44	44	44	43	43	43	43	42	42	42	41	41	40	40	39
15	G.p.m.	25	50	75	100	125	150	175	199	223	247	271	295	318	341	364	386	408	430	451
	Spread	45	45	45	45	45	45	45	45	45	44	44	44	43	43	42	42	41	41	40
16	G.p.m.	26	52	78	104	130	155	180	205	230	255	280	305	324	353	377	400	423	445	467
	Spread	46	46	46	46	46	46	46	46	46	46	45	45	44	44	43	43	42	42	41
17	G.p.m.	26	52	78	104	130	156	182	208	234	260	286	311	336	361	385	409	433	456	479
	Spread	48	48	48	47	47	47	47	47	47	47	46	46	46	45	45	44	43	43	42
18	G.p.m.	27	54	81	108	135	162	189	216	243	269	295	321	347	372	397	422	446	470	493
	Spread	49	49	49	48	48	48	48	48	48	48	47	47	47	46	46	45	44	44	43
19	G.p.m.	28	56	84	112	140	168	196	224	251	278	305	332	358	384	410	435	460	484	508
	Spread	49	49	49	49	49	49	49	49	49	49	48	48	48	47	47	46	45	45	44
20	G.p.m.	29	58	87	116	145	173	201	229	257	285	313	340	367	394	420	446	472	497	522
	Spread	50	50	50	50	50	50	50	50	50	49	49	49	48	48	48	47	46	46	45

[1] Furnished by a manufacturer.

Friction-Loss Tables. Tables 11-7, 11-8, and 11-9 have been compiled for determining friction losses in the principal types of pipe used for sprinkler system main lines. The tables are based on Scobey's formula using accepted friction coefficient values (K_s) as shown. Table 11-7 is used for portable aluminum irrigation pipe with couplers under average coupler loss conditions, table 11-8 for asbestos-cement pipe which is usually buried, and table 11-9 for welded steel pipe, which is also buried.

Other types of pipe material are available and practical for sprinkler system main lines. As a general rule, each manufacturer of pipe material has friction-loss tables available for the particular class of pipe offered. It is impractical to include all such tables in this handbook, and the designer should obtain, from the manufacturers, appropriate loss tables for pipe materials other than those included here.

Most friction-loss tables furnished by manufacturers are for new pipe unless otherwise stated. The designer should make allowance for aging of the pipe by adding a percentage of the loss consistent with the type of material and the average life of the pipe.

General Design Procedure. The loss in pressure caused by friction is the primary consideration in the design of any pipe system. The basic problems vary depending on the source of pressure as discussed as follows.

Where the pressure required for sprinkler-system operation is supplied by pumping, the problem is one of selecting main-line pipe sizes and pipe materials that will result in a reasonable balance between annual pumping costs and the capitalized cost of the pipe. The ultimate objective is to arrive at a design that results in the lowest annual water-application cost.

Normal procedure is to assume, within a reasonable range, several values of allowable head loss due to friction in main lines and submains and to compute the pipe size or sizes for each assumed value. The pipe sizes thus obtained are then checked for power economy, as discussed here, and the most economical sizes are selected. Experience shows that head-loss values assumed over a range of 10 to 40 feet as the first step in this procedure will prove adequate.

Where gravity pressure, or pressure gained by elevation differences, is utilized, one of two problems may arise. Where elevation differences are scarcely enough to provide adequate pressure for operation of the system, the problem becomes one of conservation of energy, using larger pipe sizes to reduce friction losses and avoid booster pumping where possible. Where elevation differences are considerably in excess of those required to provide normal operating pressure, the problem becomes one of reducing pressure gains, using smaller pipe sizes to increase friction losses. On excessively steep slopes, this procedure is required for the protection of the main line itself or for other equipment in the system.

Table 11-7.--Friction loss in feet per 100 feet in main lines of portable aluminum pipe with couplings

(Based on Scobey's formula (K_s = .40) and 30-foot pipe lengths)[1]

Flow (gallons per minute)	3-inch[2] (2.914)	4-inch[2] (3.906)	5-inch[2] (4.896)	6-inch[2] (5.884)	7-inch[2] (6.872)	8-inch[2] (7.856)	10-inch[2] (9.818)
40	0.658	0.157					
50	1.006	.239					
60	1.423	.339					
70	1.906	.449	0.150				
80	2.457	.584	.193				
90	3.073	.731	.242				
100	3.754	.893	.295	0.120			
120	5.307	1.263	.417	.170			
140	7.113	1.693	.560	.227			
160	9.169	2.182	.721	.293			
180	11.47	2.729	.967	.366			
200	14.01	3.333	1.102	.448	0.209		
220	16.79	3.996	1.321	.537	.251		
240	19.81	4.713	1.558	.633	.296		
260	23.06	5.488	1.814	.737	.344		
280	26.55	6.316	2.089	.849	.397		
300	30.27	7.203	2.381	.967	.452	0.235	
320	34.22	8.142	2.692	1.094	.511	.265	
340	38.39	9.137	3.020	1.227	.573	.298	
360	42.80	10.18	3.366	1.368	.639	.332	
380	47.43	11.29	3.731	1.516	.708	.368	
400	52.28	12.44	4.113	1.671	.781	.399	0.136
420		13.65	4.513	1.833	.857	.445	.149
440		14.57	4.930	1.988	.936	.486	.163
460		16.23	5.364	2.179	1.019	.529	.177
480		17.59	5.815	2.363	1.104	.573	.192
500		19.01	6.284	2.554	1.193	.620	.208
550		22.79	7.532	3.060	1.430	.742	.249
600		26.88	8.886	3.611	1.687	.876	.294
650		31.30	10.35	4.204	1.965	1.020	.342
700		36.03	11.91	4.839	2.262	1.174	.394
750		41.08	13.58	5.517	2.520	1.339	.449
800			15.35	6.237	2.915	1.513	.507
850			17.22	6.999	3.271	1.698	.569
900			19.20	7.801	3.646	1.893	.635
950			21.28	8.645	4.041	2.097	.703
1000			23.45	9.530	4.454	2.312	.775
1100			28.11	11.42	5.338	2.771	.929
1200			31.75	13.58	6.298	3.269	1.096

See footnotes at end of table.

Table 11-7.--Friction loss in feet per 100 feet in main lines of portable aluminum pipe with couplings--Continued

Flow (gallons per minute)	3-inch[2] (2.914)	4-inch[2] (3.906)	5-inch[2] (4.896)	6-inch[2] (5.884)	7-inch[2] (6.872)	8-inch[2] (7.856)	10-inch[2] (9.818)
1300				15.69	7.333	3.806	1.277
1400				18.06	8.441	4.382	1.470
1500				20.59	9.624	4.996	1.675
1600				23.28	10.88	5.648	1.894
1700				26.12	12.21	6.337	2.125
1800					13.61	7.064	2.369
1900					15.08	7.829	2.625
2000					16.62	8.630	2.894

[1] Where 20-ft. sections of pipe are used, increase values shown in the table by 7.0 percent.
Where 40-ft. sections of pipe are used, decrease values shown in the table by 3.0 percent.
[2] Outside diameter, inside diameter in parentheses.

Table 11-8.--Friction loss in feet per 100 feet in asbestos cement pressure pipe

Flow (gallons per minute)	Nominal pipe diameter in inches-- 4	6	8	10	12
	I.D. = 3.95	I.D. = 5.85	I.D. = 7.85	I.D. = 10.00	I.D. = 12.00
100	0.677				
120	.954				
140	1.28				
160	1.65				
180	2.06				
200	2.53	0.372			
220	3.03	.447			
240	3.56	.525			
260	4.16	.611			
280	4.77	.705			
300	5.44	.803			
320	6.16	.910			
340	6.91	1.02			
360	7.70	1.14			
380	8.54	1.26			
400	9.40	1.39	0.324		
420	10.3	1.52	.355		
440	11.3	1.66	.389		
460	12.3	1.81	.423		
480	13.3	1.96	.458		
500	14.4	2.12	.495		
550	17.2	2.55	.594		
600	20.3	2.99	.701	0.214	
650	23.7	3.49	.818	.249	
700	27.3	4.02	.935	.287	
750	31.1	4.57	1.07	.328	
800		5.18	1.21	.370	0.152
850		5.81	1.36	.415	.170
900		6.46	1.51	.464	.190
950		7.17	1.68	.511	.210
1000		7.91	1.85	.564	.232
1100		9.45	2.21	.675	.278
1200		11.2	2.62	.800	.328
1300		13.0	3.04	.932	.384
1400		15.0	3.50	1.07	.438
1500		17.1	3.99	1.22	.502
1600		19.3	4.52	1.38	.566
1700			5.06	1.55	.637
1800			5.67	1.73	.710
1900			6.26	1.91	.787
2000			6.90	2.11	.864
2200			8.27	2.53	1.04
2400			9.75	2.98	1.23
2600			11.4	3.47	1.43
2800			13.1	4.00	1.64
3000			14.9	4.56	1.87

From Scobey's formula

$$H_f = K_s \frac{V^{1.9}}{D^{1.1}}$$

where H_f = head loss in 1000 feet of pipe

K_s = roughness coefficient = 0.32

V = velocity in feet per second

D = inside pipe diameter in feet

Table 11-9.--Friction loss in feet per 100 feet in main lines of welded steel pipe 15 years old

(Based on Scobey's formula--K_s = .36)

Flow gallons per minute	4-inch[1]			5-inch[1]		6-inch[1]		7-inch[1]		8-inch[1]		10-inch[1]	
	16-gage	14-gage	12-gage	14-gage	12-gage	14-gage	12-gage	14-gage	12-gage	14-gage	12-gage	14-gage	12-gage
40	0.150	0.155	0.169	0.048	0.052								
50	.218	.227	.246	.074	.080								
60	.300	.312	.339	.106	.113								
70	.393	.411	.444	.142	.151								
80	.558	.579	.628	.182	.193	0.074	0.079						
90	.677	.709	.768	.228	.242	.091	.096						
100	.810	.848	.920	.279	.296	.109	.115	0.052	0.054				
125	1.28	1.34	1.45	.425	.452	.172	.181	.079	.082				
150	1.76	1.83	1.99	.602	.640	.235	.249	.111	.116				
175	2.42	2.52	2.73	.807	.857	.323	.341	.148	.155	0.075	0.080		
200	3.04	3.17	3.44	1.04	1.10	.407	.429	.191	.200	.096	.100		
250	4.79	5.01	5.43	1.59	1.69	.643	.678	.292	.306	.152	.159	0.050	0.052
300	6.74	7.04	7.63	2.25	2.39	.903	.953	.414	.432	.215	.223	.070	.072
350	8.99	9.41	10.2	3.01	3.23	1.21	1.27	.555	.579	.287	.297	.095	.097
400	11.5	12.1	13.1	3.88	4.12	1.55	1.63	.714	.746	.369	.381	.120	.124
450	14.4	15.3	16.3	4.85	5.16	1.94	2.04	.894	.934	.458	.476	.150	.155
500	17.6	18.6	19.9	5.93	6.30	2.36	2.49	1.09	1.14	.559	.580	.183	.189
600				8.38	8.91	3.39	3.57	1.54	1.61	.801	.834	.263	.271
700				11.2	11.9	4.51	4.76	2.07	2.16	1.07	1.11	.352	.361
800				14.5	15.4	5.79	6.10	2.67	2.79	1.37	1.42	.450	.464
900						7.28	7.68	3.34	3.48	1.73	1.79	.573	.584
1000						8.90	9.38	4.08	4.26	2.11	2.18	.694	.712
1200						12.5	13.2	5.76	6.02	3.04	3.07	.977	1.00
1400								7.73	8.07	3.98	4.14	1.30	1.35
1600								9.96	10.4	5.13	5.33	1.68	1.74
1800										6.43	6.66	2.12	2.17
2000										7.86	8.18	2.62	2.65
2500										12.0	12.5	3.97	4.05
3000												5.52	5.74

[1] Outside diameters.

<u>Design With Single Lateral</u>. When only one lateral line is moved along one or both sides of a main line, selecting the main-line pipe size is relatively simple. The pipe size may be selected directly from tables 11-7, 11-8, or 11-9, being the size that will result in a friction loss not exceeding the allowable limit, when the lateral is operating from the distal end of the main line.

Where two laterals are being moved along a main line but are not rotated in split-line operation, the problem is the same as if a single lateral were being used. The size of pipe selected will be that which will result in a friction loss within allowable limits when both laterals are discharging from the distal end of the main.

<u>Design With Split-Line Layout</u>. The split-line layout consists of two or more laterals rotated around the main line or submain. Its purpose is twofold: (1) To equalize the load at the pump regardless of lateral position, and (2) to minimize the haulback of lateral line pipe to the beginning point.

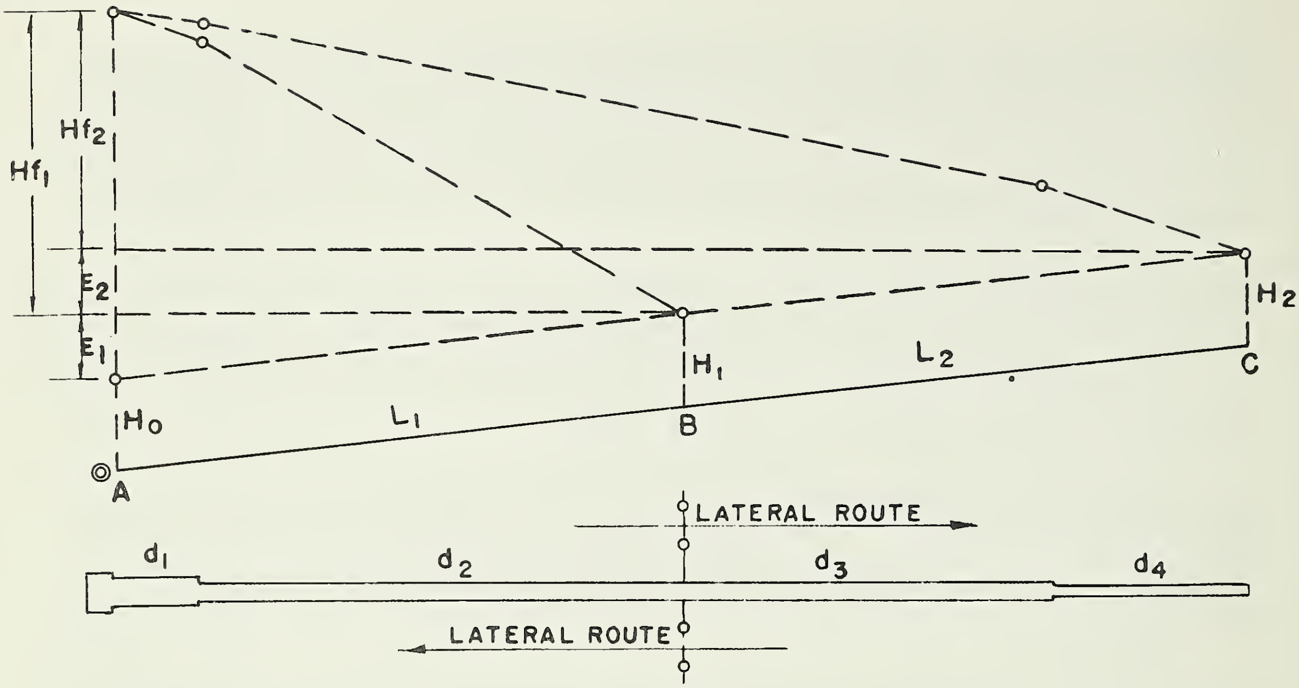
Figure 11-15 illustrates the problem of main-line design, using a split-line layout. In this layout, one lateral is moved up one side of the main line while the other is moved down the other side.

In this layout, it is apparent that at times the full quantity of water (Q) will have to be carried from A to B. At such times there will be no flow beyond B. From B to C, the flow will never exceed Q/2, and when one lateral is operating at C, requiring a flow of Q/2, at that point, the other lateral will be at A, thus the flow for the entire length of main will be Q/2.

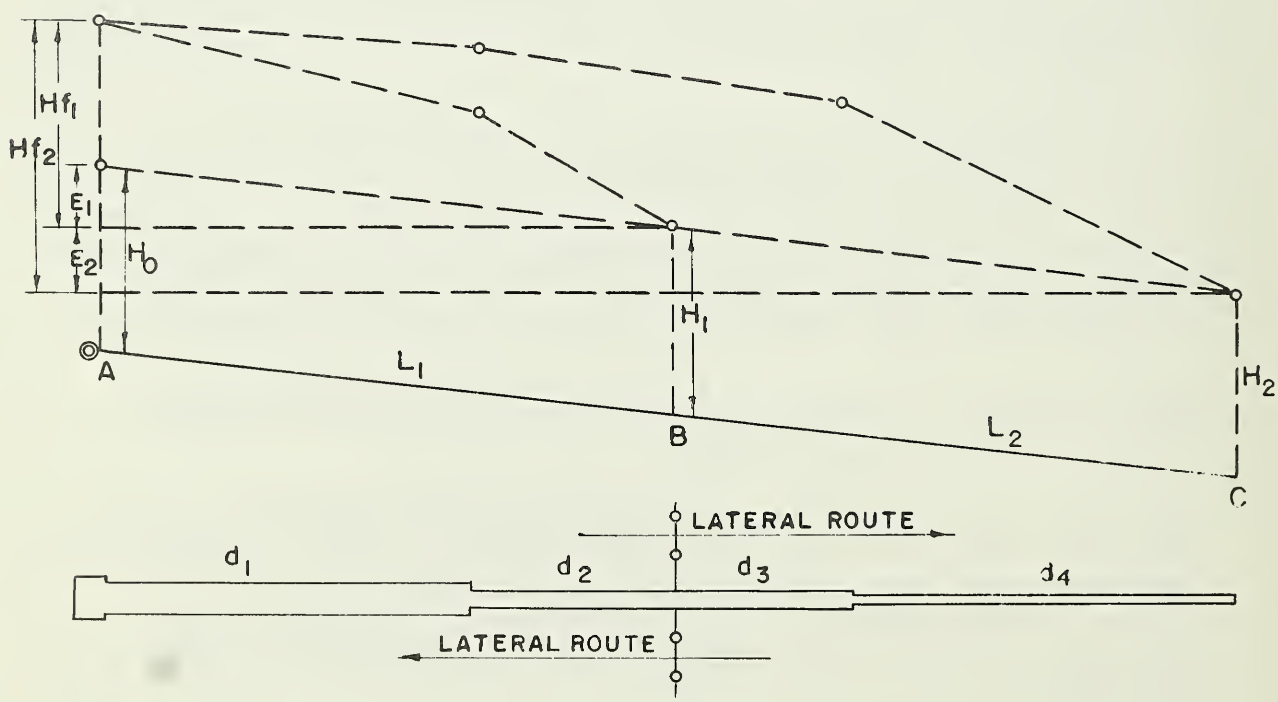
For any given total head at the pump, the smallest pipe sizes will be the ones that result in equal values for H_{f_1} and $H_{f_2}+E_2$. After pipe sizes have been computed for any reasonable value for head loss, adjustments can be made to balance annual pumping costs and capitalized pipe costs. For mains fed from pressure systems, the available head is fixed, and the smallest pipe sizes that will deliver the required flow to the laterals should be used.

A simple procedure to follow in determining minimum pipe sizes for a given limit of head loss follows:

1. Find pipe size from tables 11-7, 11-8, or 11-9, whichever applies, that will carry the flow in the first length of main L_1, with a friction loss equal to or just larger than allowed.
2. If the friction loss for length of pipe (L_1) using the selected pipe size, exceeds the H_{f_1} limit, find friction loss in next larger size pipe.



A_MAIN LINE RUNNING UPHILL



B_MAIN LINE RUNNING DOWNHILL

Figure 11-15.--Design of main line with twin laterals, split-line operation.

3. Determine the proportionate lengths for L_1 for the two pipe sizes from the equation

$$X\left(h_{f_{d_2}}\right)+(L_1-X)\,h_{f_{d_1}} = H_{f_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where X = length of smaller pipe

L_1-X = length of larger pipe

$h_{f_{d_1}}$ = rate of friction loss for the larger pipe in feet per foot

$h_{f_{d_2}}$ = rate of friction loss for the smaller pipe in feet per foot

H_{f_1} = limit of friction loss in length of pipe (L_1)

From equation (1)

$$X = \frac{H_{f_1} - h_{f_{d_1}} L_1}{h_{f_{d_2}} - h_{f_{d_1}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Thus the smallest pipe sizes for length (L_1) that will limit friction head loss to H_{f_1} are determined.

4. Determine the pipe-size requirements for length of pipe (L_2) from the equation

$$H_{f_2} = \left[h_{f_{d_1}} L_{d_1}\right] + \left[h_{f_{d_2}} L_{d_2}\right] + \left[h_{f_{d_3}} (L_2-Y)\right] + \left[h_{f_{d_4}} Y\right] \quad \ldots\ldots\ldots \quad (3)$$

where Y = length of smaller pipe

L_2-Y = length of larger pipe

$h_{f_{d_1}}$ = rate of friction loss for pipe of diameter d_1 in feet per foot

$h_{f_{d_2}}$ = rate of friction loss for pipe of diameter d_2 in feet per foot

$h_{f_{d_3}}$ = rate of friction loss for pipe of diameter d_3 in feet per foot

$h_{f_{d_4}}$ = rate of friction loss for pipe of diameter d_4 in feet per foot

L_{d_1} = length of pipe of diameter d_1

L_{d_2} = length of pipe of diameter d_2

h_{f_2} = limit of friction loss in entire main line

From equation (3)

$$Y = \frac{H_{f_2} - h_{f_{d_1}} L_{d_1} - h_{f_{d_2}} L_{d_2} - h_{f_{d_3}} L_2}{h_{f_{d_4}} - h_{f_{d_3}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Sample calculation 11-8 illustrates the problem of main-line design where two laterals are operated in a split-line manner.

Sample calculation 11-8.--Main line uphill with twin laterals split-line operation

---

Given:

Refer to figure 11-15, A.

Q, Capacity of system: 480 gallons per minute.

Length of supply line (water source to design area): 425 feet aluminum pipe (30-foot sections).

L, Length of main line (within design area): 1200 feet aluminum pipe (30-foot sections).

L_1 = 600 feet L_2 = 600 feet

$H_o = H_1 = H_2$ = 125 feet (head required to operate laterals).

$E_1 = E_2$ = 7.0 feet (elevation difference in main line assuming uniform slope).

Total allowable head loss due to friction: 35.0 feet.

Find:

Smallest pipe sizes for both supply line and main line that will limit friction head to 35.0 feet.

Calculation:

Assume diameter of supply line to be 6 inches.

From table 11-7, friction loss in 6-inch pipe for 480 gallons per minute = 2.36 feet per 100 feet.

Friction loss in 425-foot supply line = 4.25 x 2.36 = 10.0 feet.

Then H_{f_2} = 35.0-10.0 = 25.0 feet and $H_{f_1} = H_{f_2} + E_2$ = 25.0+7.0 = 32.0 feet

H_{f_1} is greater than H_{f_2} by E_2 for the reason that, when both laterals are operating at position B, the pump is not operating against static head E_2, thus advantage can be taken of this fact by increasing the allowable friction loss in section A to B.

When both laterals are operating from position B

Q = 480 gallons per minute L_1 = 600 feet

Average loss through length $L_1 = H_{f_1} \div L_1 = \frac{32.0}{600}$ = .0533 foot per foot

From table 11-7, 5- and 6-inch pipe are indicated.

For diameter d_2, friction loss in 5-inch pipe,

$$h_{f_{d_2}} = .0582 \text{ foot per foot}$$

For diameter d_1, friction loss in 6-inch pipe,

$$h_{f_{d_1}} = .0236 \text{ foot per foot}$$

Let X = Length of d_2 or 5-inch pipe, then

600-X = Length of d_1 or 6-inch pipe.

Then from equation (2)

$$X = \frac{H_{f_1} - h_{f_{d_1}} L_1}{h_{f_{d_2}} - h_{f_{d_1}}} = \frac{32.0 - (.0236 \times 600)}{.0582 - .0236} = 516$$

Use 510 feet of 5-inch pipe, and 600 - 510 = 90 feet of 6-inch pipe.

When one lateral is operating from position A and the other is operating from position C.

Q = 240 gallons per minute $\quad L_2 = 600$ feet

Average loss through length $L_2 = H_{f_2} \div L_2 = \frac{25}{600} = .0417$ foot per foot

From table 11-7, 4- and 5-inch pipe are indicated.

For diameter d_4, friction loss in 4-inch pipe,

$$h_{f_{d_4}} = .0471 \text{ foot per foot}$$

For diamter d_3 and d_2, friction loss in 5-inch pipe

$$h_{f_{d_3}} = h_{f_{d_2}} = .0156 \text{ foot per foot}$$

For diameter d_1, friction loss in 6-inch pipe,

$$h_{f_{d_1}} = .00633 \text{ foot per foot}$$

Let Y = Length of d_4 or 4-inch pipe, then

600 - Y = Length of d_3 or 5-inch pipe.

Then from equation (4)

$$Y = \frac{H_{f_2} - h_{f_{d_1}} L_{d_1} - h_{f_{d_2}} L_{d_2} - h_{f_{d_3}} L_2}{h_{f_{d_4}} - h_{f_{d_3}}}$$

$$Y = \frac{25.0 - (.00633 \times 90) - (.0156 \times 510) - (.0156 \times 600)}{.0471 - .0156}$$

$$Y = 226$$

Use 210 feet of 4-inch pipe, and 600-210 = 390 feet of 5-inch pipe.

The main line will then be composed of:

90 feet of 6-inch pipe
900 feet of 5-inch pipe
210 feet of 4-inch pipe

Similar calculations should be made for different assumed values of allowable friction head loss (H_f) to determine most economical pipe sizes.

Design with Multiple Laterals in Rotation. Where more than two laterals are operated and the flow in the main line is split, part being taken out at the first lateral and the rest continuing in the main to serve other laterals, the design problem becomes more complex (fig. 11-16).

No simple mathematical computations can be used to determine the minimum pipe sizes. Approximation of minimum sizes, however, can be made by inspection and trial and error calculations.

As a starting point, it may be assumed that the total allowable friction loss should be distributed in a straight line for flows reaching the far end of the main. The allowable loss for each reach of main will then be proportional to the length of reach.

Using the method and formula developed for the split-line design, the minimum pipe sizes can be determined for each reach of main line to fit the allowable head-loss values for that reach. The resulting head-loss line will approximate the straight line loss and will coincide with the straight line at each control point as shown on the profile (fig. 11-16).

The main thus designed will satisfy the requirements for operation with one lateral at the far end of the main. It must then be checked to see that it will satisfy the requirements for operation with laterals in other positions on the line. If the design does not satisfy the requirements for all operating conditions, adjustments will have to be made.

After a satisfactory design has been completed for a given total allowable friction head loss, similar designs for other values of head loss can be used in balancing pipe and power costs (sample calculation 11-9).

Sample calculation 11-9.--Main line with five laterals split-line operation

---

Given:

Refer to figure 11-16.

Q, Capacity of system: 355 gallons per minute. Number of laterals: 5.

q, Capacity of each lateral: $\frac{355}{5}$ = 71 gallons per minute.

L, Length of main line: 1300 feet. Portable aluminum pipe (K_s = .40).

Pressure line supply (20-ft. sections).

E, Total difference in elevation: 23.0 feet (uniform slope).

H_f, Allowable friction head loss: 20.1 feet.

Find:

Smallest pipe sizes for main line that limit total friction and elevation (static) head to 20.1+23.0 = 43.1 feet.

In this problem when one lateral is operating at the far end of the main at D, two laterals are operating at C, and the other two at B, as shown in plan (A). Plan (B) shows the lateral locations when the least length of main is being used. In this plan, one lateral operates at E, two at F, and two at G. Plan (C) shows the lateral locations at an intermediate move between plan (A) and plan (B). In plan (C), no two laterals operate off the same outlet on the main.

Note that with the layout shown, the laterals will have to be moved 13 times, and 1 lateral will need be operated an extra set to cover the field.

An inspection of the three plans shows that 355 gallons per minute will never be carried beyond B, 284 gallons per minute beyond F, 213 gallons per minute beyond C, and 142 gallons per minute beyond G. The end 240 feet of main will never carry more than 71 gallons per minute.

Calculation:

Start the solution by assuming that the 20.1-foot friction head loss (H_f) will be distributed in an approximate straight line when system is operating under conditions as shown on plan (A). The average rate of loss will then be $H_f/L = \frac{20.1}{1300}$ = .0155 foot per foot.

Allowable friction losses for each reach of main line will be:

Reach A to B, 300 feet x .0155 = 4.65 feet (H_{f_1})

Reach B to C, 520 feet x .0155 = 8.04 feet (H_{f_1})

Reach C to D, 480 feet x .0155 = 7.44 feet (H_{f_1})

For reach A to B, Q = 355 gallons per minute. Table 11-7 indicates 5- and 6-inch pipe.

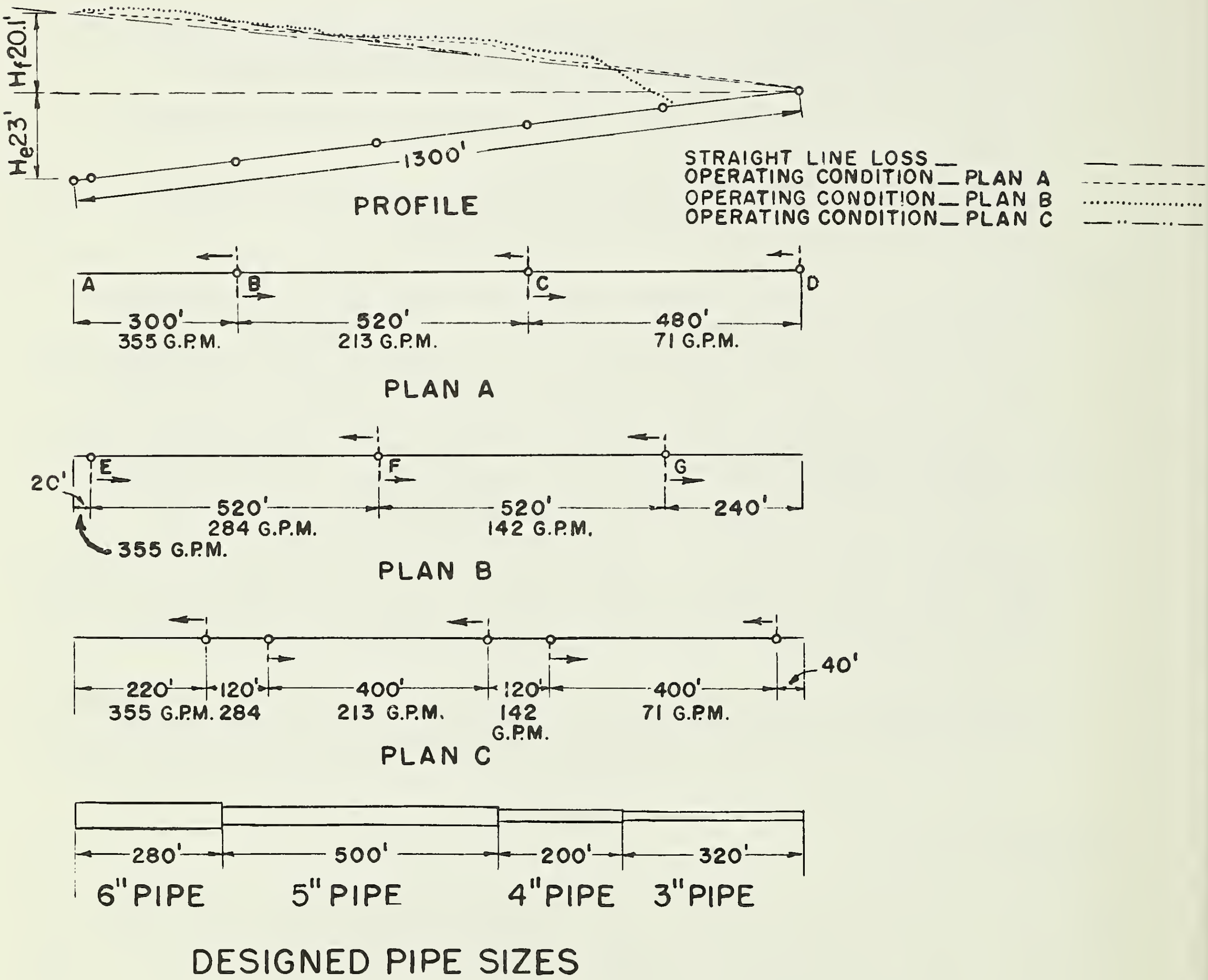


Figure 11-16.--Design of main line with five laterals, split-line operation.

Let X = Length of 5-inch pipe with rate of friction loss =

.0351 foot per foot $(h_{f_{d_2}})$.

300-X = Length of 6-inch pipe with rate of friction loss =

.0143 foot per foot $(h_{f_{d_1}})$.

Using equation (2)

$$X = \frac{4.65 - (.0143 \times 300)}{.0351 - .0143} = 17 \text{ feet. Use 20 feet of 5-inch pipe.}$$

300-X = 300-20 = 280 feet of 6-inch pipe.

For reach B to C, Q = 213 gallons per minute. Table 11-7 indicates 4- and 5-inch pipe.

Let X = Length of 4-inch pipe with rate of friction loss =

.0403 foot per foot $(h_{f_{d_2}})$.

520-X = Length of 5-inch pipe with rate of friction loss =

.0133 foot per foot $(h_{f_{d_1}})$.

Using equation (2)

$$X = \frac{8.04 - (.0133 \times 520)}{.0403 - .0133} = 41. \text{ Use 40 feet of 4-inch pipe.}$$

520-X = 520-40 = 480 feet of 5-inch pipe.

For reach C to D, Q = 71 gallons per minute. Table 11-7 indicates 3- and 4-inch pipe.

Let X = Length of 3-inch pipe with rate of friction loss =

.0210 foot per foot $(h_{f_{d_2}})$

480-X = Length of 4-inch pipe with rate of friction loss =

.00494 foot per foot $(h_{f_{d_1}})$

Using equation (2)

$$X = \frac{7.44 - (.00494 \times 480)}{.0210 - .00494} = 316. \text{ Use 320 feet of 3-inch pipe.}$$

480-X = 480-320 = 160 feet of 4-inch pipe.

The main line will then be composed of:

280 feet of 6-inch pipe.
500 feet of 5-inch pipe.
200 feet of 4-inch pipe.
320 feet of 3-inch pipe.

The friction loss distribution would approximate a straight line between points A and D and would coincide with the straight line of each control point as shown on the profile (fig. 11-16).

Check the line mathematically or graphically for operating conditions as shown on plan (B) and on plan (C). When the system is operating under conditions as shown on plan (B), (allowable loss $= 20.1 + \frac{240 \times 23}{1300} = 24.3$ feet).

355 gallons per minute through	20 ft.	of 6-in. pipe at .0143	=	0.29 ft.
284 gallons per minute through	260 ft.	of 6-in. pipe at .00934	=	2.43 ft.
284 gallons per minute through	260 ft.	of 5-in. pipe at .0230	=	5.98 ft.
142 gallons per minute through	240 ft.	of 5-in. pipe at .00616	=	1.48 ft.
142 gallons per minute through	200 ft.	of 4-in. pipe at .0186	=	3.72 ft.
142 gallons per minute through	80 ft.	of 3-in. pipe at .0783	=	6.26 ft.
	1060 ft.	Total	=	20.16 ft. (OK)

When the system is operating under conditions as shown on plan (C) (allowable loss $= 20.1 + \frac{40 \times 23}{1300} = 20.8$ feet).

355 gallons per minute through	220 ft.	of 6-in. pipe at .0143	=	3.15 ft.
284 gallons per minute through	60 ft.	of 6-in. pipe at .00934	=	.56 ft.
284 gallons per minute through	60 ft.	of 5-in. pipe at .0230	=	1.38 ft.
213 gallons per minute through	400 ft.	of 5-in. pipe at .0133	=	5.32 ft.
142 gallons per minute through	40 ft.	of 5-in. pipe at .00616	=	.25 ft.
142 gallons per minute through	80 ft.	of 4-in. pipe at .0186	=	1.49 ft.
71 gallons per minute through	120 ft.	of 4-in. pipe at .00494	=	.59 ft.
71 gallons per minute through	280 ft.	of 3-in. pipe at .0210	=	5.88 ft.
	1260 ft.	Total	=	18.62 ft. (OK)

The main line as designed will limit friction losses to those allowable operating under all conditions. If the total loss under plans (A) or (B) had been more than those allowable, an adjustment would have been necessary. The adjustment could be made by reducing the length of 3-inch pipe and increasing the length of 4-inch pipe.

Design of Main and Submain Layout. Where several submains are used to operate laterals, the design of the main-line system is a series of individual problems where the maximum operating-head requirements for each submain must be computed. The solution for minimum pipe sizes consistent with allowable head loss is similar to the main-line-design problem in sample calculations 11-8 and 11-9. Figure 11-17 illustrates how the maximum head requirements at the pump are determined on the basis of the

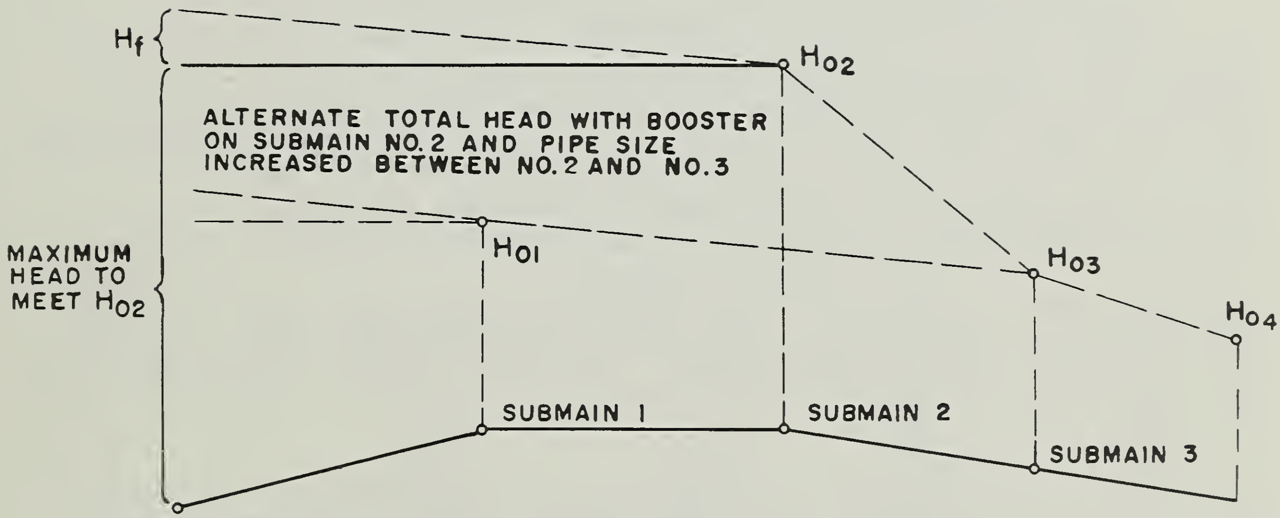


Figure 11-17.--Maximum operating conditions with submains.

maximum requirements for a submain (2). In this case, if the submain serves a small part of the total area, a booster pump might be used, thus reducing the requirements at the main pump as shown by the alternate line.

Determining Most Economical Pipe Sizes. The most economical size or combination of sizes of pipe in a main line or submain is that which will result in a reasonable balance between the annual cost of owning the pipe and the annual pumping cost. This balance depends primarily on two factors: (1) The seasonal hours of operation, and (2) cost of the power used.

For example, in humid areas a system may be operated for 500 hours per season, or less, and power rates may be comparatively low. Then the annual cost of pumping against friction head is low and a reduction in main-line pipe sizes would ordinarily be justifiable. On the other hand, in an area where full-season operation is required and power costs are high, pumping against friction head becomes much more costly. An increase in main-line pipe sizes is often required to achieve balance.

Sometimes after a number of cost comparisons have been made to determine economical pipe sizes (sample calculation 11-10), limits in allowable friction losses become apparent for local seasonal operating hours and power costs.

In sample calculation 11-10, several values of allowable friction head loss are assumed and pipe sizes required for each determined. The annual pipe-cost differences are compared with annual pumping-cost differences between the sizes of pipe required for the assumed friction head-loss values.

The annual pipe-cost difference between two computed sizes or combinations of sizes of pipe in a main line are determined by amortizing the initial pipe-cost difference over a period equal to the estimated life of the pipe at prevailing interest rates compounded. The appropriate amortization factor, taken from table 11-10, is applied to the initial pipe-cost difference. This factor includes the annual charge due to depreciation of the pipe plus the compounded interest paid for use of the money invested.

The annual pumping-cost differences are determined from the following formulas:

For electric motors

$$\text{Hourly pumping costs} = \frac{Qhc}{5310\ Ee} \text{ in cents}$$

where Q = discharge in gallons per minute
h = pumping head in feet (in this case the difference in assumed friction head loss)
c = cost of power in cents per kilowatt hour
E = pump efficiency
e = efficiency of the electric motor

For internal combustion engines

$$\text{Hourly pumping costs} = \frac{QhF_c c}{3960\ E} \text{ in cents}$$

where Q = discharge in gallons per minute
h = pumping head in feet
F_c = fuel consumption in gallons per horsepower hour
c = cost of fuel in cents per gallon
E = pump efficiency.

Annual pumping-cost differences are obtained by multiplying hourly pumping-cost differences by the estimated seasonal operating hours.

A further discussion of pumping costs is included in chapter 8, Irrigation Pumping Plants.

Table 11-10.--Amortization factors

Estimated life (years)	Compound interest rates			
	3 percent	4 percent	5 percent	6 percent
5	0.21835	0.22463	0.23097	0.23740
10	.11723	.12329	.12950	.13587
15	.08377	.08994	.09634	.10296
20	.06722	.07358	.08024	.08718
25	.05743	.06401	.07095	.07823
30	.05102	.05783	.06505	.07265
40	.04326	.05052	.05828	.06646

Sample calculation 11-10.--Determining most economical pipe sizes for main lines

Given:

Main line with two laterals operating in a split-line layout.
Q, Capacity: 600 gallons per minute.
L, Length of main: 1320 feet.
No elevation difference along line.
Quick-coupling aluminum pipe, K_s = .40 (30-ft. sections)
Assumed life of pipe: 15 years.
Pipe costs per foot are:

8-inch	$2.35;
6-inch	1.65;
5-inch	1.23;
4-inch	.92;

c, Cost of electric power: 1.5¢ per kilowatt hour.
e, Efficiency of electric motor: 85 percent

E, Pump efficiency: 65 percent
Estimated seasonal operation: 480 hours (humid area)

Find:

Most economical pipe sizes, or those which will result in a reasonable balance between pipe costs and pumping costs.

Calculation:

Using the procedure illustrated by sample calculation 11-8, determine the required pipe sizes for several assumed values of allowable friction head loss (H_f), as follows:

Assumed values H_f	Length of pipe required 8-inch	6-inch	5-inch	4-inch
	Feet	*Feet*	*Feet*	*Feet*
15	340	680	300	
25		660	620	40
35		460	660	200
45		280	700	340

Using these pipe size and length combinations and current prices of each diameter pipe, compute the total pipe cost for each value of H_f and the pipe-cost differences between these values. Compute annual pipe-cost differences by amortizing the total cost differences over the estimated 15-year life of the pipe using an interest rate of 5 percent. The amortization factor (0.09634) is from table 11-10. These calculations are as follows:

Values H_f	Total pipe cost	Cost difference	Amortization factor	Annual pipe-cost difference
	Dollars	*Dollars*		*Dollars*
15	2196.00			
		307.60	0.09634	29.63
25	1888.40			
		133.60	.09634	12.87
35	1754.80			
		119.00	.09634	11.46
45	1635.80			

Compute the hourly pumping cost of overcoming the 10.0-foot head interval between assumed values of H_f

$$\text{Hourly cost} = \frac{Qhc}{5310Ee} = \frac{600 \times 10 \times 1.5}{5310 \times 0.65 \times 0.85} = 3.07¢$$

Compute annual pumping cost for this 10-foot head interval by multiplying the hourly cost by the estimated seasonal operating hours:

3.07¢ x 480 hours = $14.74 per year.

Comparing this annual pumping-cost difference with the annual pipe-cost differences shows that the results favor the pipe sizes required for a friction head-loss value, H_f = 25 feet. If H_f were dropped to 15 feet, the annual savings in pumping cost would be only $14.74, while the annual increase in cost of the pipe would be $29.63. Similarly, if H_f were raised to 35 feet, the annual savings in pipe costs would be only $12.87, while the annual increase in pumping cost would be $14.74.

Note: If the system were used only 300 hours per year, pipe sizes obtained from an H_f value of 45 feet would be more economical. If the system were operated in an arid area for as much as 1000 hours per year, the pipe sizes obtained by using an H_f value of 15 feet or less would be most economical.

Portable Versus Buried Main Lines. Buried main lines are restricted to areas that are to be irrigated permanently, whereas portable main lines can be used on all areas. Aside from this restriction on the use of main lines, the choice between portable and buried mains and between different pipe materials is largely a matter of economics.

Portable main lines have an advantage over buried main lines in that they can be moved about, and, in most cases, a greater area can be covered with the same length of pipe. For example, if the water source were located in the center of a rectangular design area, the length of portable main-line pipe required would be only half that required for buried pipe. However, if the water source were located at one end or side of the area, the lengths of pipe required would be the same for both types of mains. Another advantage of portable main lines is that no installation costs are involved.

Buried main lines have some distinct advantages over portable main lines. The materials used in buried main-line pipe and the fact that the pipe is not handled after initial installation contribute to a much longer life for this type of line. Thus for the same length and size of main line, the annual fixed cost for buried main lines is usually lower than that for portable lines. There is a considerable saving in the labor required to move portable lines within the design area and to and from the place of storage at the start and end of the irrigation season.

Buried lines do not interfere with planting, cultural, or harvesting operations.

Sample calculation 11-11 illustrates the procedure in making an economic comparison. This comparison is based on annual fixed costs of the pipe and does not include the labor savings favoring buried lines. There would also be some difference in annual fixed costs due to the greater number of takeout valves required along the buried line. This difference would not be great enough to influence the choice between the two types of lines.

Sample calculation 11-11.--Comparison of annual fixed costs of portable and buried main lines

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Given:

Water source at center of field one-half mile in length.
Length of portable main line required: 1300 feet.
Length of buried main line required: 2600 feet.
Capacity, Q = 850 gallons per minute.
Assumed allowable friction head loss: 23.0 feet.
Cost of 8-inch portable aluminum pipe: $2.50 per foot.
Cost of 8-inch asbestos-cement pipe (installed): $2.20 per foot.
Cost of 6-inch asbestos-cement pipe (installed): $1.58 per foot.
Interest rate: 5 percent.

Find:

Fixed annual costs of main line using portable aluminum pipe and buried asbestos-cement pipe.

Calculation:

Using tables 11-7 and 11-8, find the pipe sizes required for each type of pipe to be:

Aluminum pipe with couplers: 1300 feet of 8-inch
Asbestos-cement pipe: 2360 feet of 8-inch and 240 feet of 6-inch
Total cost of aluminum pipe: 1300x2.50 = $3250.00

Estimated life of aluminum pipe: 15 years.
Amortization factor from table 11-10 = .09634.
Annual fixed costs: 3250.00x.09634 = $313.10.

Total cost of asbestos-cement pipe:	2360x2.20 =	$5192.00
plus	240x1.58 =	379.20
		$5571.20

Estimated life of asbestos-cement pipe: 40 years.
Amortization factor from table 11-10: .05828.
Annual fixed costs: 5571.20x.05828 = $324.69.

In this case, the portable aluminum main line has the lowest annual fixed cost. The inconvenience and expense of moving the portable line from one side of the field to the other and back again, however, will amount to more than the difference in annual fixed costs ($11.59) between the two types.

Design for Continuous Operation. Most irrigators prefer a sprinkler system that may be operated continuously without having to stop the pump each time a lateral line is uncoupled and moved to the next position. In the case of portable main lines, valve-tee couplers are placed at each lateral position and each lateral line is equipped with a quick-coupling valve opening elbow. The elbows on the laterals open and close the valves in the couplers, thus permitting the flow of water from the main to be turned on or off at will. Where buried main lines are used,

takeoff or hydrant valves are placed on top of the riser serving the same purpose as the valve-tee couplers in portable lines.

One or more extra lateral lines are often used so that lateral lines may be moved from one position to another while others are in use, thereby permitting uninterrupted operation.

This type of operation offers several advantages: (1) It eliminates long walks to the pump and back each time a lateral line is uncoupled and moved, (2) it takes less people, and (3) one or two men, moving lateral lines while other lines are operating, can keep a relatively large system operating continuously.

Pressure Requirements

To select a pump and power unit that will operate the system efficiently, it is necessary to determine the total of all pressure losses in the system or the total dynamic head against which water must be pumped. Sketches showing the various losses that contribute to the total dynamic head are shown for both centrifugal and turbine pumps in chapter 8, Irrigation Pumping Plants.

Where operating conditions will vary considerably with the movement of lateral lines and main line or with a change in the number of sprinklers operated, both the maximum and minimum total dynamic head must be computed.

The pressure head required to operate lateral lines and to overcome friction losses in main lines and submains has already been discussed. Other head losses for which pressure at the pump must be provided are discussed in succeeding paragraphs.

Losses in Fittings and Valves. Allowance must be made for friction losses in all elbows, tees, crossings, reducers, increasers, adapters, and valves placed in lateral lines, main lines, or submains and in the suction line. Where deep-well turbine pumps are used, losses in the column must be considered. Pump manufacturers make allowances for losses in the pump itself.

Losses in fittings and valves are computed by the formula

$$h_f = K \frac{V^2}{2g}$$

where h_f = friction head loss in feet
K = resistance coefficient for the fitting or valve
$\frac{V^2}{2g}$ = velocity head in feet for a given discharge and diameter

Values of the resistance coefficient (K) may be taken from table 11-11, and values of the velocity head $\left(\frac{V^2}{2g}\right)$ may be taken from table 11-12.

Table 11-11.--Values of resistance coefficient K for use in formula $h_f = K \frac{V^2}{2g}$ for fittings and valves

IRRIGATION PIPE

Fitting or valve	Nominal diameter--							Source of authority
	3-inch	4-inch	5-inch	6-inch	7-inch	8-inch	10-inch	
Elbows:								
90° Standard								
45° Standard								
90° Long Sweep								
45° Long Sweep								
Reducing								
Bends:								
90° Standard								
45° Standard								
Tees:								
Branch closed								
Line to branch								
Branch to line			Table to be completed when data become available.					
Crosses:								
Branches closed								
Line to 1 branch								
Line to both branches								
Reducers								
Valves:								
Straight line								
Valve tee coupler								
Valve opening elbow								
Control wyes:								
One branch closed								
Both branches open								
STANDARD PIPE								
Elbows:								
Regular flanged 90°	0.34	0.31	0.30	0.28	0.27	0.26	0.25	Pipe friction manual
Long radius flanged 90°	.25	.22	.20	.18	.17	.15	.14	Hydraulic Institute
Long radius flanged 45°	.19	.18	.18	.17	.17	.17	.16	Same as above
Regular screwed 90°	.80	.70						Same as above
Long radius screwed 90°	.30	.23						Same as above
Regular screwed 45°	.30	.28						Same as above

Table 11-11.--Values of resistance coefficient K for use in formula $h_f = K \frac{V^2}{2g}$ for fittings and valves--Continued

STANDARD PIPE

Fitting or valve	Nominal diameter--							Source or authority
	3-inch	4-inch	5-inch	6-inch	7-inch	8-inch	10-inch	
Bends:								
Return flanged	0.33	0.30	0.29	0.28	0.27	0.25	0.24	Pipe Friction Manual
Return screwed	.80	.70						Hydraulic Institute
Tees:								
Flanged line flow	.16	.14	.13	.12	.11	.10	.09	Same as above
Flanged branch flow	.73	.68	.65	.60	.58	.56	.52	Same as above
Screwed line flow	.90	.90						Same as above
Screwed branch flow	1.20	1.10						Same as above
Valves:								
Globe flanged	7.0	6.3	6.0	5.8	5.7	5.6	5.5	Same as above
Globe screwed	6.0	5.7						Same as above
Gate flanged	.21	.16	.13	.11	.09	.075	.06	Same as above
Gate screwed	.14	.12						Same as above
Swing check flanged	2.0	2.0	2.0	2.0	2.0	2.0	2.0	Same as above
Swing check screwed	2.1	2.0						Same as above
Angle flanged	2.2	2.1	2.0	2.0	2.0	2.0	2.0	Same as above
Angle screwed	1.3	1.0						Same as above
Foot	.80	.80	.80	.80	.80	.80	.80	Same as above
Strainers-basket type	1.25	1.05	.95	.85	.80	.75	.67	Same as above

OTHER

Fitting or valve	K		Source or authority
Inlets or entrances:			
Inward projecting	.78	All diameters	King's Handbook
Sharp cornered	.50	All diameters	King's Handbook
Slightly rounded	.23	All diameters	King's Handbook
Bell-mouth	.04	All diameters	King's Handbook
Sudden enlargements	$K = \left(1 - \frac{d_1^2}{d_2^2}\right)^2$ where d_1 = diameter of smaller pipe		S.I.A. Handbook
Sudden contractions	$K = 0.7\left(1 - \frac{d_1^2}{d_2^2}\right)^2$ where d_1 = diameter of smaller pipe		S.I.A. and King

Table 11-12.--Values of velocity head $\left(\frac{V^2}{2g}\right)$ for aluminum pipe

Flow (gallons per minute)	3-inch[1] (2.914)	4-inch[1] (3.906)	5-inch[1] (4.896)	6-inch[1] (5.884)	7-inch[1] (6.872)	8-inch[1] (7.856)	10-inch[1] (9.818)
50	0.090	0.028					
100	.359	.111	0.045	0.021			
150	.809	.250	.101	.049			
200	1.438	.445	.180	.086	0.046		
250	2.246	.696	.282	.135	.085		
300	3.235	1.002	.406	.195	.105	0.061	
350	4.402	1.364	.552	.265	.142	.083	
400	5.750	1.781	.722	.346	.186	.109	0.044
450		2.255	.913	.438	.235	.138	.056
500		2.783	1.127	.540	.290	.170	.070
550		3.368	1.364	.654	.351	.206	.084
600		4.008	1.623	.778	.418	.245	.100
650		4.704	1.906	.913	.491	.287	.118
700		5.455	2.210	1.059	.569	.333	.137
750		6.262	2.537	1.216	.654	.383	.157
800			2.886	1.384	.744	.435	.178
850			3.258	1.562	.840	.492	.201
900			3.653	1.751	.941	.551	.226
950			4.070	1.951	1.049	.614	.252
1000			4.510	2.162	1.162	.680	.279
1100			5.457	2.616	1.406	.823	.337
1200			6.494	3.113	1.673	.980	.402
1300				3.654	1.964	1.150	.471
1400				4.238	2.278	1.333	.547
1500				4.865	2.615	1.531	.627
1600				5.535	2.975	1.742	.714
1700				6.248	3.358	1.966	.806
1800					3.765	2.204	.904
1900					4.195	2.456	1.007
2000					4.648	2.722	1.116

[1] Outside diameter; inside diameter in parentheses.

<u>Static Head</u>. Static head is the difference in elevation between the water source and the point of discharge or the vertical distance the water must be raised or lowered. Static head, therefore, may be a plus or a minus factor.

Static head in lateral lines has been considered in the design procedure for determining the pressure required for lateral operation (P_m) and need not be considered here.

The differences in elevation between the pump and the highest and lowest points on the main line (or submain where used) give the maximum and minimum static-head values. These must be included in computating the total dynamic head for maximum and minimum operating conditions.

Suction lift, or the difference between the elevation of the water source and the elevation of the pump, is a form of static head that must be included in total head computations. For wells, the drawdown while pumping at the maximum required discharge is also included.

Velocity Head. Since the velocity of flow in a sprinkler system will seldom exceed 8 feet per second, the velocity head $\left(\frac{V^2}{2g}\right)$ will seldom exceed 1 foot and therefore may be disregarded.

Total Dynamic Head. Summarizing then, the total dynamic head consists of:

1. Pressure head required to operate lateral lines in feet.
2. Friction head losses in the main line and submains.
3. Friction head losses in fittings and valves.
4. Total static head including suction lift.

Selection of Pump and Power Unit

Having determined the range of operating conditions (maximum and minimum capacities and total dynamic heads), the pump and power unit may be selected in accordance with the procedures in chapter 8, Irrigation Pumping Plants.

Sprinkler Irrigation Efficiencies

Several factors affect the water-application efficiency of sprinkler irrigation systems:

1. Variation of individual sprinkler discharge along lateral lines. This variation can be held to a minimum by proper lateral design.
2. Variation in moisture distribution within the sprinkler-spacing area. This variation is caused primarily by wind movement and can be only partially overcome by spacing the sprinkler to meet adverse wind conditions. In addition to the variation caused by wind, there is always a variability in the distribution pattern of individual sprinklers. The extent of this variability depends on sprinkler design, operating pressure, and sprinkler rotation.
3. Loss of water by direct evaporation from the spray. This loss is increased as temperature and wind velocities increase and little, if anything can be done to control it.
4. Loss of water retained on the plant foliage. This loss will be lowest percentagewise when larger applications are made.
5. Evaporation from the soil surface before the water is utilized by the plants. This loss will also be lowest percentagewise when greater depths are applied.

Table 11-13 can be used as a rough guide to sprinkler-irrigation efficiencies. More locally adapted information may oftentimes be obtained from the local irrigation guide.

Table 11-13.--Water-application efficiencies for well-planned sprinkler systems[1]

Depth of water applied per irrigation (acre-inches per acre)	Average wind movement, 0-4 mile per hour	
	Application rate under 0.5	Inches per hour more than 0.5
	Percent	*Percent*
Under 2.0	65	70
More than 2.0	70	75
	Average wind movement, 4-10 miles per hour	
Under 2.0	60	65
More than 2.0	65	70
	Average wind movement, 10-15 miles per hour	
Under 2.0	55	60
More than 2.0	60	65

[1] Use efficiencies 5 percent higher than shown for areas where peak consumptive use rates are less than 0.20 inch per day and for undertree irrigation in all areas.

Information from tables such as table 11-13 can be only general in nature. There is a real need for the measurement and evaluation of sprinkler-irrigation efficiencies under field conditions in all areas where this method of irrigation is used.

The procedure for evaluating sprinkler-irrigation systems is discussed in U. S. Department of Agriculture Agricultural Handbook 82, Methods for Evaluating Irrigation Systems, 1956.

Mechanized Sprinkler Equipment

Attempts have been made to reduce the work in moving portable lateral lines from one setting to the next. In recent years, several manufacturers have been working on the development of at least four types of mechanized sprinkler laterals described briefly as follows:

The cost of all these mechanized laterals is greater than that for comparable hand-move equipment. For this reason, a careful cost comparison should be made between the added expense of the equipment and the estimated savings in labor. This is particularly important in humid areas where sprinkler equipment may be used as little as 300 hours per year.

Side-Roll Laterals. The side-roll lateral system, one of the first mechanized sprinkler laterals, utilizes the lateral-line pipe as an axle with wheels either at each coupler or attached around the pipe away from the coupler. Where wheels are placed at the coupler, the wheel hub and coupler are combined and designed to be as "quick coupling" as possible.

Features of this type of system include: (1) Drain valves to drain the pipe before moving, (2) hand- or power-driven moving devices for rolling the lines to a new position, (3) wind brakes to prevent wind from blowing the lines across the field, and (4) hose connections or telescope sections to connect to water source or to connect more than one section of the lateral.

Apparent limitations are:

1. Limited to close-growing forage crops, small grains, or low-growing row crops.
2. Labor requirements increased on odd-shaped fields.
3. Not easily dismantled for movement from field to field.
4. Straightening and shifting required on rolling lands because of difference in travel length across the field.
5. Equipment cost 1.6 to 2.0 times the cost of comparable hand-move laterals.

Drag-Type Laterals. The drag-type of sprinkler lateral appeared first as a homemade affair, using boiler tubing welded together, and was pulled back and forth into orchard rows. This system was put on the market in 1948 and sold first for use on pastures. Features of this system include: (1) A clamp-type coupler with a selfdraining arrangement (another arrangement is skid pans clamped on the lateral, each skid straddling a standard hand-move coupler), (2) an outrigging made up of two skids to prevent overturning, and (3) a hose connection to attach to water source. The entire line is pulled from one setting to another, swinging over into the new lateral position as the line is pulled forward the same way trains are switched from one track to another.

Limitations of this system are:

1. Limited to well-sodded forage crops.
2. Limited to nonabrasive soils if heavy wear on the pipe is to be avoided.
3. Crop damage precludes use for bringing up seedings.
4. Initial cost 1.2 to 1.5 times the cost of comparable hand-move lines.

Pull-Type Wheel Laterals. The first system was put on the market in 1948. The system is moved the same way as the drag-type but has supporting wheel carriages to raise the pipe off the ground during moving. The wheel carriages differ, however, in design and resulting flexibility.

Some have swivel wheels and can be pulled either endways or sideways.

Limitations of the pull-type wheel system are:

1. Limited to close-growing forage crops or to strips between row-crop strips.
2. Limited to medium-textured to sandy soils for bare ground use, e.g., bringing up seed seedings.
3. Crop damage varies with ability of lateral to track during moving.
4. Initial cost 1.4 to 1.6 times the cost of comparable hand-move lines.

Selfpropelled Laterals. A selfpropelled or continuous moving sprinkler was placed on the market in 1953. This system operates by swinging the lateral, suspended by wheel supports and cables, around a circle, with the water source at the center of a square field.

Sprinkler discharge and coverage are increased outward to the end of the line to compensate for increasing area coverage away from the center. Close to the center, sprinklers may be automatically turned off and on to reduce the application rate. Wheel carriages are driven by hydraulic cylinders, automatically controlled for proportional rate of travel.

Apparent limitations in its present stage are:

1. Limited to square tracts without division fencing.
2. Limited to flat, even topography.
3. Limited range of water application.
4. Questionable uniformity of water application.
5. Initial cost several times that for comparable hand-move equipment.

Special Uses for Sprinkler Equipment

The introduction of light-weight aluminum tubing and quick-action couplers has led to several companion uses of sprinkler equipment on the farm. The more important are discussed in succeeding paragraphs.

Applying Fertilizers. Dissolving soluble fertilizers in water and applying the solution through a sprinkler system is quick, economical, easy, and effective. A minimum of equipment is required, and once the apparatus for adding the fertilizer to the irrigation water is set up, the crop being irrigated can be fertilized with less effort than is required for mechanical application.

Penetration of the fertilizer into the soil can be regulated by the time of application in relation to the total irrigation period. The fertilizer can be dissolved in water in a barrel or closed container, in the approximate ratio of 1 pound of fertilizer per gallon of water.

There are several advantages in using sprinkler-irrigation systems as a means of distributing fertilizers. First, both irrigation and fertilization can be accomplished with only slightly more labor than is required

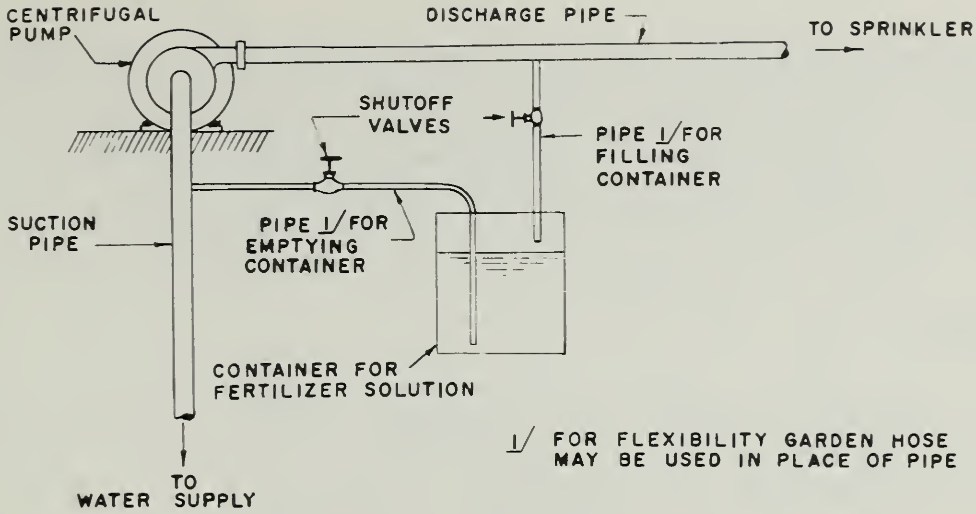


Figure 11-18.--A method for adding fertilizers in solution to a centrifugal pump system.

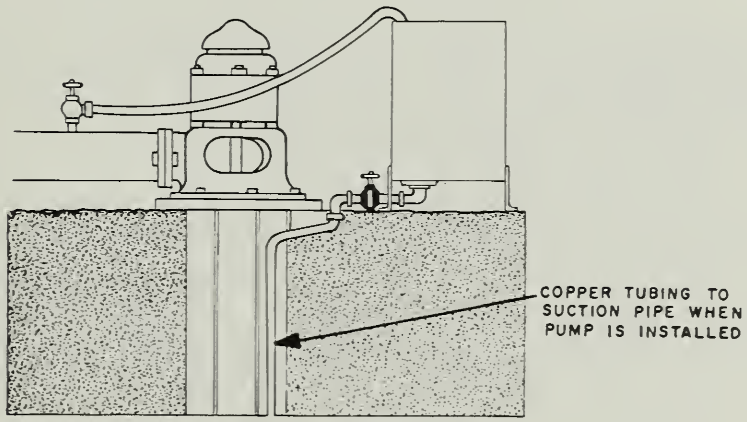


Figure 11-19.--A method for adding fertilizers in solution to a deep-well turbine pump system.

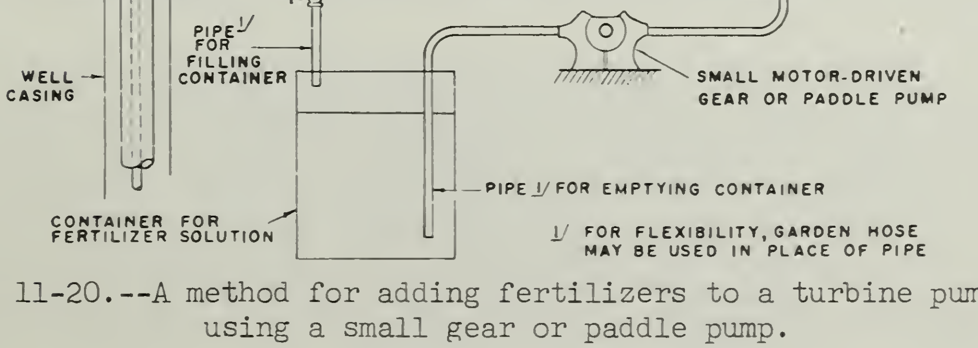


Figure 11-20.--A method for adding fertilizers to a turbine pump system using a small gear or paddle pump.

for irrigation alone. This is particularly important in arid and semi-arid areas where the applications of irrigation water and fertilizers can, in most cases, be scheduled to coincide. Secondly, close control can usually be maintained over the placement depth of fertilizer as well as over lateral distribution. The uniformity of fertilizer distribution, however, can be only as good as the uniformity of water distribution. But, if the sprinkler system has been properly designed, acceptable fertilizer distribution will result along with proper water distribution.

The simplest method of applying fertilizer through a sprinkler system is to introduce the solution into the system at the suction side of a centrifugal pump (fig. 11-18). A pipe or hose is run from a point near the bottom of the fertilizer-solution container to the suction pipe of the pump. A shutoff valve is placed in this line for regulatory purposes. Another pipe or hose from the discharge side of the pump to the fertilizer container provides an easy method of filling the container and dissolving the fertilizer and for rinsing. If a closed pressure-type container is used, such as one of the several fertilizer applicators on the market, the line from the discharge side of the pump can be left open and the entrance of the solution into the water regulated by the valve into the suction side of the line.

A variation of this method for deep-well turbine pumps is to extend a copper tube down along the outside of the pump column to a point below the pump bowls where the suction pipe is tapped. This tube, clamped onto the column as the pump is installed in sections, leads to the bottom of the fertilizer container (fig. 11-19). A copper tube 3/8 to 1/2 inch in diameter lessens the possibility of clogging. The solution is put in the system the same way as into a centrifugal pump system.

Fertilizers can also be added to sprinkler systems with a small high pressure pump such as a gear pump or paddle pump (fig. 11-20). If a spray rig for orchards is available, the fertilizer solution can be pumped with the small pump on the spray rig. This method can also be used in applying fertilizer to individual sprinkler lines where more than one sprinkler line is operating at one time, however, it may be more cumbersome to move around than other types of injectors. To avoid corrosion after the fertilizer solution is pumped into the line, the barrel or container should be refilled and water run through the pump, repeating the operation several times to rinse the pump and barrel thoroughly.

One common method of applying fertilizer through sprinkler systems is with an aspirator unit. A part of the water discharged from the pump is bypassed through the aspirator, creating suction that draws the fertilizer solution into the line. The principle is to create a pressure drop between the intake and outlet of the pressure-type container, thus creating a flow through the container into the sprinkler main line or lateral. Several commercial fertilizer applicators are on the market. One of these uses a Venturi section, inserted into the pipeline, utilizing the pressure gradient through the Venturi.

A second type generally utilizes pressure drop created by a pipe enlargement or swedge blister that creates sufficient pressure gradient without flow restriction. It is essential to have valves for regulating the flow through the aspirator and the main line. The cost of this type of fertilizer applicator is about the same as a small gear or paddle pump unit. It has the advantage of simplicity and freedom from moving parts.

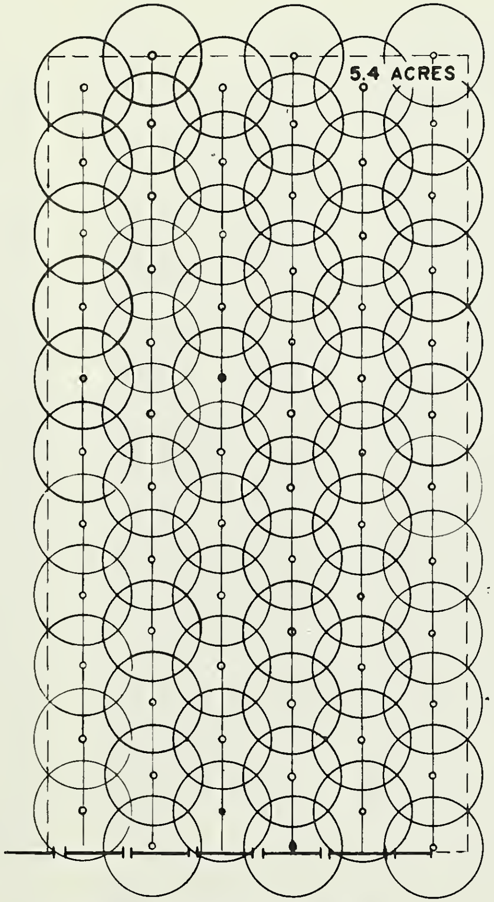
The common procedure followed in applying fertilizer through sprinkler systems consists of three time intervals. During the first interval, the system operates normally, wetting the foliage and the soil. During the second interval, the fertilizer is injected into the system. This application should rarely be less than 30 minutes and preferably an hour or longer. This eliminates the possibility of poor distribution due to slow or uneven rotation of sprinklers. Also, with normal fertilizer-application rates, the solution passing through the system will be more diluted. This lessens the possibility of foliage burn or damage to the system parts by corrosion.

The last time interval should be long enough to completely rinse the system with clear water and remove all fertilizer from plant foliage. Depending on the rate of application at which the system is operating, this last rinseoff should be between 30 minutes, for fast rates, and 1-1/2 hours, for slower rates. The last time interval also has the effect of moving the fertilizer down into the crop-root zone.

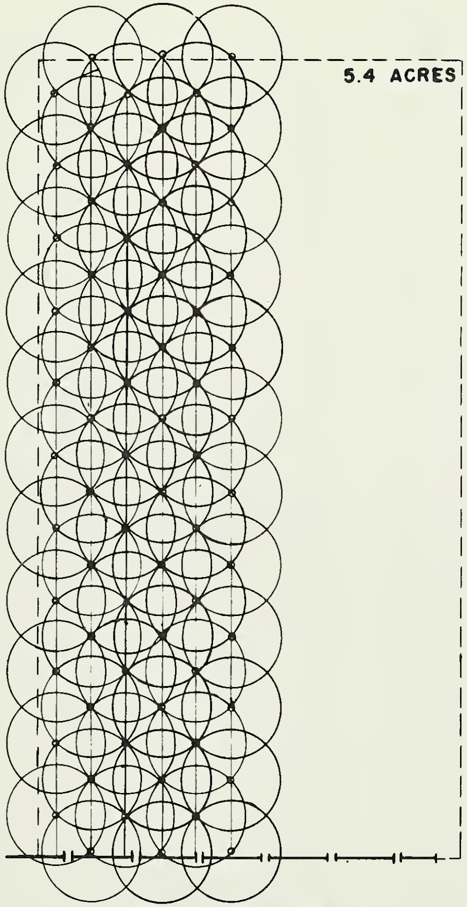
Applying Soil Amendments. Various soluble soil amendments, such as gypsum, sulphuric acid, limes, and soluble resins, can be applied through sprinkler systems. In the San Joaquin Valley of California, the application of gypsum is an essential farming practice on many soils in order to reduce the percentage of soluble sodium and to avoid deflocculation and poor infiltration of the soils. In this area, it is common practice to introduce gypsum through sprinkler-irrigation systems. The methods used are generally the same as those used to add soluble fertilizers.

Frost Protection. Sprinkler irrigation systems can and are being used for frost protection; however, the ordinary system is limited because of the area it can cover with any one setting of the lateral lines. Therefore, for adequate protection of most areas, it is necessary to add lateral lines and sprinklers at the predetermined spacing so that the entire field can be covered with a fine mist of water during freezing temperatures (fig. 11-21).

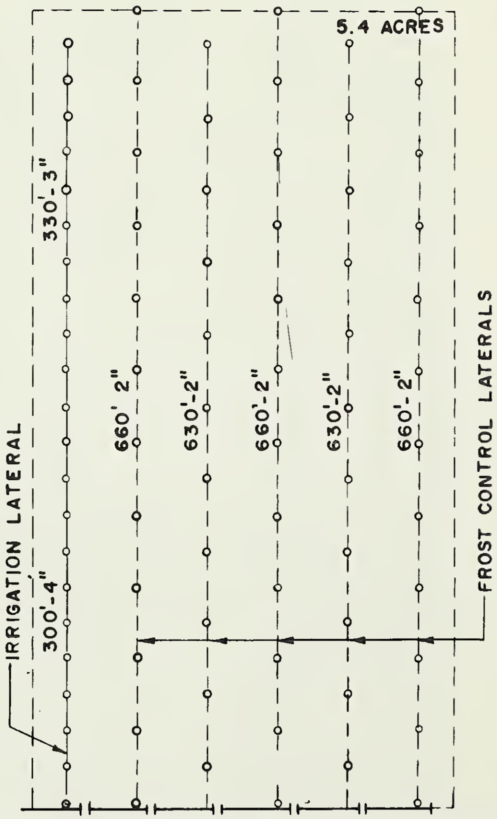
The wetted area from one sprinkler should just meet or overlap a few feet the wetted area from the next sprinkler, thus providing adequate coverage to a larger area. To distribute the water satisfactorily to this larger area, the sprinklers should be spaced in a triangular pattern. Application rates of about one-tenth to 1/8 inch per hour appear adequate. This means using very small-sized single nozzle sprinklers. Sprinklers with two or more nozzles usually apply more water than is needed. Two nozzle sprinklers can be used by plugging one nozzle and using only the nozzle with the "kicker arm." Nozzle sizes 1/8 inch to



PLAN A-FROST CONTROL
6 laterals 60'x60' spacing
Sprinklers staggered
69-5/32"No.20 R.B. sprinklers
Sprinkler capacity 4.4 g.p.m.
Average pressure 40 p.s.i.
Total discharge=304 g.p.m.
Rate of application=0.12" per hr.
2" lateral lines



PLAN A-IRRIGATION
6 laterals at 60'x 30' spacing
Sprinklers staggered.
69-5/32" No.20 R.B. sprinklers
Sprinkler capacity 4.4 g.p.m.
Average pressure 40 p.s.i.
Total discharge 304 g.p.m.
Rate of application 0.23" per hr.
2 settings required



PLAN B-IRRIGATION AND FROST CONTROL
Irrigation:
1 lateral- 30' x 60' spacing
22- 13/64" x 5/32" No.40 R.B sprinklers
Sprinkler capacity=11.8 g.p.m.
Average pressure=40 p.s.i.
Total discharge=260 g.p.m.
Rate of application= 0.63" per hr.
Frost control:
Use the 22 No.40 sprinklers and plug the 13/64" opening.
Add 47- 5/32" sprinklers

Figure 11-21.--Plans for frost protection with a sprinkler-irrigation system.

1/4 inch have been used successfully, with the size depending on the spacing. The 1/8- and 5/32-inch nozzles are satisfactory on a 60 by 60-foot triangular spacing, the 3/16- and 7/32-inch on an 80 by 80-foot, and the 1/4-inch on a 90 by 90-foot spacing if the operating pressure is sufficient to provide a wetted diameter large enough to cover the entire area between sprinklers. Studies at Michigan State University indicate that the rotation speed of small single-nozzle sprinklers should be 20 seconds or less per revolution for proper control.

The frost-protection system should be turned on sometime before air temperatures at plant level reach 32° F. Most growers believe that applying water until the ice melts is the best technique. The field becomes a mass of ice and yet the ice remains at a temperature above the freezing point of the plant liquid as long as the water is being applied. Damage generally occurs if the water is turned off too soon after the air temperature is above 32°. Therefore, for adequate protection, one should continue to apply water until the air temperature is above 32° F. and all the ice has melted off the plants.

Some type of electric alarm system should be installed so that the farmer will know when to get up at night to turn on the system. A thermoswitch set in the field at plant level with wires to the house and with a loud bell alarm will serve this purpose. The switch should be set so that the bell sounds when the plant-level temperature reaches 34°. The system should be laid out and tested well in advance of the time that it may have to be used.

Frost protection with sprinklers has been used successfully on low-growing vegetable crops such as tomatoes, cucumbers, peppers, and beans and on cranberries and strawberries. During low-temperature frosts the ice that accumulates on trees can be heavy enough to break the branches. Similar ice accumulation could break down sweet corn, celery, pole beans, and tall flowers. Tall, thin plants are not generally adapted to this method of frost protection.

Applying Insecticides and Weed-Control Chemicals. From time to time, attempts have been made to inject insecticides, fungicides, and weed-control chemicals through sprinkler systems in a way similar to that described for applying fertilizer. Information to date is not for anyone to conclude whether such practices are successful. The high dilution, together with almost immediate washoff, however, would make the success of this practice highly doubtful. While this method of applying these chemicals cannot be recommended at present, additional research and field trials may lead to a procedure that, at some future date, will prove successful.

Other Uses. There are numerous other uses for sprinkler-irrigation equipment, both on the farm and elsewhere. Since they are not directly related to the purposes of this handbook, they are not discussed but merely listed:

1. Farm fire protection.

2. Cannery waste disposal.
3. Log curing.
4. Cooling of buildings (poultry).
5. Moisture control for earthfill construction.
6. Snow making (recreation).

Installation and Operation of Sprinkler Systems

An effort has been made to provide SCS engineers with information, data, and design procedures that should aid in preparing good sound sprinkler-irrigation plans. The best prepared plan, however, contributes little or nothing toward obtaining the objective of conservation irrigation and maximum yields of high-quality crops unless the farmer purchases substantially the equipment specified in the plan, installs the equipment properly, and operates it according to design.

Data Furnished Farmer. A plan of the system should be furnished the farmer. Such a plan should include a map of the design area or areas showing the location of the water supply and pumping plant; the location of supply lines, main lines, and submains; the location and direction of movement of lateral lines; the spacing of sprinklers; and the pipe sizes and lengths of each required. While it is not necessary to furnish the farmer with a complete list of materials, minimum equipment specifications should be furnished. These include the discharge-operating pressure and wetted diameter of the sprinklers, the capacity of the pump at the design dynamic head, and the horsepower requirements of the power unit. Fittings for continuous operation should be specified where applicable.

Purchase of Equipment. In past years, many farmers received sprinkler-system plans prepared by SCS engineers, and then purchased equipment that varied or was entirely different from that specified in the plans. While SCS personnel does not have any responsibility for or control over the purchase of sprinkler equipment by the farmer, it is important, nevertheless, to make every effort to familiarize him with the necessity for purchasing the proper equipment as specified in his plan.

Assistance with Installation and Operation. The supplier of sprinkler equipment is expected to install the system properly and to provide the user with instructions for proper operation and maintenance. This, however, does not relieve the SCS of the responsibility of providing the farmer with such onsite assistance as may be required to attain the objectives of conservation irrigation. The farmer should be given instruction in the layout of main lines and laterals, the spacing of sprinklers, the movement of lateral lines, the time of lateral operation, and the maintenance of design-operating pressures. He also should be shown how to estimate soil-moisture conditions in order to determine when irrigation is needed and how much water should be applied.

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